(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 729 044 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
29.01.2003 Bulletin 2003/05

(51) Int Cl.^{7}: **G02B 6/36**, C03B 19/00, C03C 10/00, G02B 6/26, G02B 6/30, G02B 6/42

(21) Application number: **96301160.6**

(22) Date of filing: **21.02.1996**

(54) Optical fiber-fixing substrate, method of producing the same and optical device

Substrat zur Befestigung einer optischen Faser, sein Herstellungsverfahren und optisches Bauelement

Substrat de fixation pour fibre optique, son procédé de fabrication et dispositif optique

(84) Designated Contracting States:
DE FR GB IT

(30) Priority: **21.02.1995 JP 5524995**
09.02.1996 JP 4681996

(43) Date of publication of application:
28.08.1996 Bulletin 1996/35

(60) Divisional application:
02006766.6 / 1 225 464

(73) Proprietor: **NGK INSULATORS, LTD.**
Nagoya City Aichi Pref. (JP)

(72) Inventors:
- **Ota, Takashi**
  Kasugai City, Aichi Pref. (JP)
- **Fukuyama, Masashi**
  Inuyama City, Aichi Pref. (JP)
- **Aisaka, Yukio**
  Kasugai City, Aichi Pref. (JP)

(74) Representative: **Paget, Hugh Charles Edward et al**
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(56) References cited:
US-A- 3 864 018

EP 0 729 044 B1

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an optical fiber-fixing substrate having a fixing groove for receiving and fixing an optical fiber therein, optical devices including such a substrate and a method of producing the substrate.

2. Description of Related Art

[0002] Various substrates are known for fixing an optical fiber having a diameter of, for example, around 125 μm. In any type of substrates, a light beam transmission loss between the optical fiber and another light beam transmitting means becomes large, if the axis of the optical fiber is fixed displacedly from a desired position. Thus, working of a very high precision, such as not over than 0.5 μm, is requested to the fixing groove of the substrate for fixing the optical fiber. Fig. 1(a) is a perspective view of an example of such a substrate, wherein a main body 2 of a substrate 34 for fixing an optical fiber is made of a glass or ceramics. A plural number of so-called V grooves 12 extend in the upper surface of the substrate main body 2 from an end towards the opposing end of the upper surface. The grooves 12 are formed parallel to each other. In the V groove 12, an inclined surface 7 extends substantially linearly between the ridge 43 and the bottom 11. Thus, the V grooves 12 have a V shaped cross-section. The respective V groove 12 is minute having a depth of around a hundred and several tens μm, for example.

[0003] US-A-3 864 018 shows substrates having parallel arrays of V-grooves for optical fibres. The material of the substrate is not specified.

[0004] In producing such a substrate for fixing an optical fiber, the V grooves may be formed by a method of etching a silicon material. However, the method has a limit in the working precision and could hardly produce the V grooves of a high precision of more than a certain extent. Thus, in order to accomplish such a high'precision, a method of forming the V grooves has been used wherein, alumina, agate, zirconia or the like ceramics is worked by grinding. In such a case, the V grooves are formed by, for example, sintering a shaped ceramics body to prepare a sintered body, plane grinding the sintered body to prepare a flat surface, and then grinding the flat surface by a diamond grinding wheel. At that time, when the grinding is effected by a diamond grinding wheel, the grinding is effected in a constant direction, so that each V groove 12 extends respectively linearly and parallel to each other from an end towards the opposing end of the flat surface of the main body 2, as shown in Fig. 1(a).

[0005] The substrate 34 having the optical fibers 9 received and fixed in the respective V groove 12 has to be optically coupled to another light beam transmitting devices. Namely, if an optical fiber is used as the another light beam transmitting device, a separate optical fiber is prepared, the end surface of the optical fiber fixed in the V groove 12 is contacted with the end surface of the separate optical fiber, and the contacted portions of the optical fibers are heated and melted to connect the optical fibers. Thereafter, the connected optical fibers are removed from the respective fixing groove.

[0006] As an alternative example, if an optical guide wave is used as the another light beam transmitting device, an optical guide wave substrate having provided an optical guide wave is prepared. Each optical fiber 9 is fixed in the respective V groove 12, and an adhesive agent layer 8 is formed around the optical fibers 9 to firmly join each optical fiber 9 to the main body 2 of the substrate 34. A lid 32 is joined onto the substrate 34 to prepare an assembly as shown in Fig. 1(b). Thereafter, the end surface 33 of the substrate 34 is polished by grinding and the end surface of the optical guide wave is polished by grinding to high precisions, the polished end surfaces of the two substrates are joined to each other, and the other end surface of the respective optical guide wave is optically coupled to the end surface of the corresponding respective optical fiber.

[0007] The substrate 34 is applicable also to a core wire selecting device as described in I. Nakanishi et al "Study of an Optical Fiber Movable Type Core Wire Selecting Device" reported in Electro Information Communication Society, Communication Society General Meeting B-651, 1995. In this case, an optical fiber is fixed until the middle of the V groove, and the end surface of the optical fiber is optically polished. A master optical fiber is received in the V groove to oppose the optically polished end surface of the already fixed optical fiber. In such a state, light beams can be passed and guided from the master optical fiber to the respective optical fiber. By this means, experiments can be performed, such as, detection of trouble of the optical core wire.

[0008] The inventors have found the following problem in the process of studying the form of such an optical fiber-fixing substrate. Namely, when the respective optical fiber 9 is received in the respective V groove 12 of the substrate 34 as shown in Fig. 1(a) and the surface of the substrate 34 is carefully observed by a survey type electron microscope, a minute defect or break-off 30 is found sometimes at a portion of the top 10 of the ridge 43 or a portion 10A of the flat surface as exaggeratedly shown in Fig. 1(a). Such a defect 30 is likely formed when the optical fibers 9 is received in the respective V groove 12. Formation of the defect 30 may have an adverse influence over the optical fiber 9, so that the substrate 34 having the defect 30 has to be discarded as a rejected part resulting in the increase of the production cost.

[0009] Particularly, in case when the optical fiber is coupled to an optical guide wave, the end surface 33 of

the substrate 34 of the assembly shown in Fig. 1(b) has to be polished by grinding as described above. However, subsequent study of the polished surface revealed sometimes a minute defect 31 at the edge of the ridge 10 or 10A. Such a defect also should not be formed, because a situation is considered that the precision of the coupled portion of the end surface of the optical guide wave and the end surface of the substrate 34 is decreased by the fragment 35 produced by the defect when coupling the both end surface to each other, or a situation is considered that deterioration of the substrate 34 proceeds from the defect 30 when the coupled article of the optical guide wave and the substrate 34 is used in a strict environmental condition for a long period of time.

[0010] In addition, in the aforedescribed optical fiber movable type core wire selecting device, the master optical fiber is inserted in the inlet or opening of the respective V groove and moved in the respective V groove towards the respective optical fiber. However, the respective master optical fiber is likely damaged when the respective master optical fiber is collided against the respective ridge at the neighborhood of the opening of the V groove. Such a damage of the master optical fiber is a problem because the inspection of the trouble of the optical core wires can not be performed.

SUMMARY OF THE INVENTION

[0011] An object of the present invention is to prevent the formation of the defect or break-off in the ridge of the fixing groove of the optical fiber-fixing substrate when an optical fiber is received in the fixing groove of the substrate or when the end surface of the substrate is polished by grinding.

[0012] Another object is also to reduce or to minimize a defect, a breakage or the like damage of the optical fiber as far as possible.

[0013] In the first aspect, the present invention is an optical fiber-fixing substrate as set out in claim 1.

[0014] The inventors have observed the form of the ridge of the fixing groove by a survey type electron microscope. As a result, the inventors have found that the ridge has a sharp top and the defect is easily formed at or around the sharp top thereby to form the defect or a fragment of the defect.

[0015] The inventors have also studied the reason why the ridge or its neighborhood has a so sharp top and found that it necessarily results from the method of forming the groove, which has heretofore been overlooked. This point will be described later with reference to the drawings.

[0016] Based on these findings, the inventors made a finding leading to the present invention that the above described phenomena of the defect or break-off or the formation of minute fragment can be prevented by imparting a curvature of radius of not less than 5 μm viewed in the lateral cross-sectional view of the fixing groove to the entire portion of the ridges of the fixing groove.

[0017] Preferably, the bottom of the fixing groove has a curvature of radius of not more than 5 μm viewed in the lateral cross-sectional view of the fixing groove. Namely, a sharp bottom is preferable. This is because, if the bottom has such a radius of curvature when the size of the optical fiber is relatively smaller than the size of the fixing groove, the optical fiber can easily contact with a dust or the like obstacle in the bottom if such obstacle is present therein. As a result, the optical axis of the optical fiber is displaced from a desired position to increase an insertion loss between another light beam transmitting means.

[0018] In the present invention, preferably the optical fiber-fixing substrate is made of a glass or ceramic, and the fixing groove of the substrate a is preferably formed by a press forming method. The reason therefor will be explained later.

Brief Description of the Drawings

[0019] For a better understanding of the present invention, reference is made to the attached drawings in which:

Fig. 1(a) is a perspective view of a conventional optical fiber-fixing substrate 34;
Fig. 1(b) is a front view of an assembly obtained by joining a lid 32 onto the substrate 34 of Fig. 1(a);
Fig. 2(a) is a plan view of an optical fiber-fixing substrate of an embodiment of the present invention;
Fig. 2(b) is a cross-sectional view of the substrate 1 of Fig. 2(a);
Fig. 2(c) is a cross-sectional view of an assembly obtained by receiving the optical fibers 9 in the respective fixing groove 3 of the substrate 1;
Fig. 3 is a cross-sectional view showing the lateral cross-section of a conventional optical fiber-fixing substrate 8;
Fig. 4 is a cross-sectional view of a mold 37 for producing the substrate 1 of Fig. 2;
Fig. 5 is a cross-sectional view of an optical fiber-fixing substrate 12 of another embodiment of the present invention;
Fig. 6 is a cross-sectional view of an optical fiber-fixing substrate 45 of a still another embodiment of the present invention;
Fig. 7(a) is a cross-sectional view of an assembly wherein an optical fiber 9A and a dust particle 16 are received in the fixing groove 3 having a sharp bottom 5;
Fig. 7(b) is a cross-sectional view of an assembly wherein the optical fiber 9A and a dust particle 16 are received in a fixing groove 17 having a round bottom 18;
Fig. 8(a) is a plan view of an optical fiber-fixing substrate 22 having a fixing groove 23 of the second

invention;

Fig. 8(b) is an enlarged cross-sectional view of and around the fixing groove 23;

Figs. 9(a) and 9(b) are schematic plan views of the fixing grooves respectively showing a planar shape thereof prepared by a different method;

Figs. 10(a) and 10(b) are plan views of optical devices respectively showing another embodiment of the present invention;

Fig. 10(c) is a side view of the optical device of Fig. 10(b);

Fig. 11(a) is a plan view of an optical fiber-fixing substrate 40 of an embodiment of the present invention;

Fig. 11(b) is a side view of the substrate 40 of Fig. 11(a);

Figs. 12(a), 12(b) and 12(c) are enlarged cross-sectional views of and around the connected portion of an end surface of an optical guide wave and an end surface of a fixing groove prepared respectively by a different method;

Figs. 13 and 14 are perspective views of optical devices respectively showing other embodiments of the present invention;

Fig. 14 is a side view of an optical device of an embodiment of the present invention;

Fig. 15(a) is a perspective view of an optical fiber-fixing substrate 24 of the present invention;

Fig. 15(b) is a plan view of the substrate 24;

Fig. 16(a) is a schematic cross-sectional view of the substrate 24 of Fig. 15 wherein an optical isolator is arranged thereon;

Fig. 16(b) is a schematic side view of an optical device wherein an end surface of the optical fiber is inclined to the vertical surface in the substrate 24;

Fig. 16(c) is a schematic cross-sectional view of an another substrate of the present invention wherein an optical isolator is arranged thereon;

Fig. 17 is a schematic side view of an optical device using an optical fiber-fixing substrate of an embodiment of the present invention;

Fig. 18(a) is a schematic side view of an optical fiber-fixing substrate 105 of another embodiment of the present invention;

Fig. 18(b) is a front view of the substrate 105 of Fig. 18(a) viewed from an end surface side thereof;

Fig. 18(c) is a front view of the substrate 105 of Fig. 18(a) viewed from the other end surface side thereof;

Fig. 19 is a photograph taken by a survey type electron microscope showing the neighborhood of the fixing groove of the substrate 45 of Fig. 6; and

Fig. 20 is a photograph taken by a survey type electron microscope showing the neighborhood of the fixing groove of the substrate 8 of Fig. 3.

Numbering in the Drawings

[0020] 1, 8, 12, 22, 24, 34, 40, 45, 49, 51: optical fiber-fixing substrate; 2: main body of substrate; 3, 3A, 3B, 12, 13, 17, 23, 50, 52, 58A, 58B, 60: fixing groove; 5: sharp bottom; 7: inclined surface; 8: adhesive agent; 9, 9A, 59A, 59B, 59C: optical fiber; 10, 10A: sharp ridge; 11, 18: round bottom; 14: flat bottom; 44, 44A, 46: ridge having a curvature of radius of at least 5 μm over the entire ridge; 47: flat surface of the ridge 46; 48: edge between the flat surface 47 and the inclined surface of the ridge 46; 55, 56: coating of the optical fiber; 63, 70, 73: optical guide wave; 65a: vertical end surface of the optical fiber; and 65b: inclined end surface of the optical fiber.

Detailed Explanation of the Invention

[0021] Hereinafter, the present invention will be explained in more detail with reference to the drawings, if necessary.

[0022] Fig. 2(a) is a plan view of an optical fiber-fixing substrate 1 of an embodiment of the present invention, Fig. 2(b) is a cross-sectional view of the substrate 1, Fig. 2(c) is a cross-sectional view of the substrate 1 wherein the optical fibers 9 are received and joined in the respective fixing-grooves 3. The substrate 1 has a desired number (for example, 6 in Fig. 2) of the fixing grooves 3 formed as an array in the main body 2. Each fixing groove 3 extends from an end surface 2a of the main body 2 to the other end surface 2b of the main body 2. As the shape of the fixing groove 3, though a so-called "V" groove is used in this embodiment, a "U" groove is also usable in the present invention.

[0023] Each V groove 3 has a pair of opposing inclined surfaces 7 and a sharp bottom 5 is formed between the opposing inclined surfaces 7. In the cross-sectional view shown in Fig. 2(b), the bottom 5 is formed to have a curvature of radius of not more than 5 μm. The bottom 5 can hardly be processed to a curvature of radius of less than 1 μm, so that a curvature of radius of not less than 1 μm is preferable from the aspect of processing.

[0024] Between each pair of the fixing grooves 3 is respectively formed a ridge 44. At the outer sides of the two outermost fixing grooves 3 is respectively formed a side 44A. Each ridge 44, 44A is formed in a cross-sectional view to have a curvature of radius of at least 5 μm in a cross-sectional view over the entire portion of the ridge. Namely, each ridge is minutely round. Here, in this embodiment, the tops 4, 4A of the ridges 44, 44A should have a curvature of radius of not less than 5 μm in a cross-sectional view, because those portions of the ridge 44, 44A other than the tops 4, 4A are linear in cross-section and thus have a curvature of radius of infinitely large.

[0025] After receiving the optical fibers 9 in the respective fixing groove 3 shown in Fig. 2(b), the end surfaces of the optical fibers 9 are disposed to oppose the end surfaces of preliminarily prepared optical fibers, and both the end surfaces of the opposing optical fibers are

melted to join to each other. Alternatively, the optical fibers 9 are received in the respective fixing groove 3 and contacted with the inclined surfaces 7 to decide their position, and then an adhesive agent is introduced and filled in the interstices between the optical fibers 9 and the fixing grooves 3 to form an adhesive agent layer 8 thereby to fix the optical fibers 9, as shown in Fig. 2(c). Thereafter, the end surfaces of the optical fibers 9 are optically coupled to an optical guide wave. It is of course possible to insert and receive the master optical fiber in the fixing groove 3 as described above.

[0026] By providing a minute round portion at the tops 4, 4A of the ridges 44, 44A of the optical fibers 9 as shown in Fig. 2, the problem of the minute defect or break-off of the ridges 44, 44A could be solved. However, for achieving such a function and an effect, the ridges should have a curvature of radius of not less than 5 μm over the entire portion of the ridges.

[0027] However, regarding the tops of the ridges, an excessively large curvature of radius of the tops may result in a situation that the inclined surfaces 7 of the fixing groove 3 will exceed a contacting point to the optical fibers 9, so that the optical fibers 9 are not positioned in the fixing grooves 3. When arranging standard optical fibers of a diameter of 125 μm in a pitch of 250 μm, a theoretically allowable curvature of radius is 90 μm at the maximum. However, from a practical viewpoint of considering an error, the ridges 4, 4A has preferably a curvature of radius of not over than 80 μm.

[0028] The inventors have studied the microscopic form of conventional optical fiber-fixing substrates as described above, and the form is schematically shown in Fig. 3 wherein the respective V groove 12 has a pair of opposing inclined surfaces 7 and a round bottom 11 between the opposing inclined surfaces 7. Between the fixing grooves 3 is respectively formed a ridge 43. At the outer sides of the two outermost fixing grooves 12 is respectively formed a ridge 43A.

[0029] Here, the inventors observed the shapes of the ridges 43, 43A and the bottoms 11 by a survey type electron microscope to find out that the ridges 43, 43A are very sharp and the tops 10, 10A of the ridges have a curvature of radius of around 1 μm in a cross-sectional view. In contrast, the bottoms 11 are minutely round in shape and have a curvature of radius of around 10 μm in a cross-sectional view. The inventors made studies on the reason of producing such a form.

[0030] In a conventional method, the surface of the main body 2 of the substrate was worked by a diamond grinding wheel to form the fixing grooves. In such a case, it is considered that the root portion of the grinding wheel could perform a relatively sharp grinding to give sharp ridges 10, 10A, meanwhile, the edge of the grinding wheel could hardly perform a sharp grinding of the bottoms 11, so that the round bottoms 11 are formed.

[0031] The inventors formed also the V grooves by etching a silicon wafer. However, the inventors have found out that sharp edges are formed at the ridges also in this case.

[0032] In contrast, the inventors have found out that the substrate having the ridges and the bottoms of the form as shown in Fig. 2 can be mass-produced by the following production method. That is, at first a mold having a desired planar shape, for example, as shown in Fig. 2(a), is prepared. Of course, the planar shape of the fixing groove in the optical fiber-fixing substrate may be varied variously by changing the planar design of the mold.

[0033] At that time, the mold 37 is provided with grooves 38 and projections 42 respectively corresponding to the shapes of the ridges 4, 4A and the fixing grooves 3 as shown in Fig. 4. The mold 37 is used in combination with the other base mold for press forming a glass or ceramics therebetween to produce the substrate 1 shown in Fig. 2. At the time of press forming, the shape of the grooves 38 is transferred to the ridges 4, 4A of the substrate 1, the shape of the projections 42 is transferred to the V grooves 3 of the substrate 1, and the shape of the inclined surfaces 41 is transferred to the inclined surfaces 7 of the substrate 1.

[0034] Here, the grooves 38 of the mold 37 should also be formed by grinding. However, by the grinding operation also, the projections 39 become sharp and the bottoms 40, 40A assume a round shape. If such a mold is used for preparing a shaped body, the resultant shaped body has the sharp bottoms 5 transferred from the sharp projections 39 of the mold, and the round ridges 4, 4A transferred from the round bottoms 40, 40A of the mold, as shown in Fig. 2(b).

[0035] Thereafter, if the resultant shaped body is made of a ceramics powder, the shaped body is degreased, the degreased shaped body is fired to obtain an optical fiber-fixing substrate. If the resultant shaped body is made of a glass, the shaped body is annealed to obtain an optical fiber-fixing substrate. Alternatively, the shaped body is heat treated to crystallize the glass, and the shaped body made of the crystallized glasses is annealed to obtain an optical fiber-fixing substrate.

[0036] Alternatively, the sharp ridges 43 shown in Fig. 3 is worked by grinding to give the edges of a curvature of radius of not less than 5 μm over the entire portions of the ridges.

[0037] The fixing grooves 13 of the substrate 12 may also have a flat surface at the bottoms 14, as shown in Fig. 5.

[0038] An optical fiber-fixing substrate 45 of a form as shown in Fig. 6 may also be produced. The substrate 45 has the bottoms 5 of a curvature of radius of not more than 5 μm. The bottoms 5 are formed between the inclined surfaces 7 of the ridges 46, and hold the respective optical fiber therein by means of an adhesive agent layer 8. The tops of the ridges 46 have respectively a flat surface 47, and edges 48 are formed between the ends of the flat surface 47 and the upper ends of the inclined surfaces 7. The edges 48 have respectively a curvature of radius of not less than 5 μm.

[0039] It is also conceivable to provide a curvature or round portion at the above described bottoms. However, in the present invention, preferably the grooves have sharper bottoms, and concretely the bottoms have a preferable curvature of radius of not more than 5 μm. The reason thereof will be explained below with reference to Fig. 7.

[0040] Fig. 7(a) shows a sharp bottom 5 in the fixing groove 3. If the optical fiber 9A is relatively smaller than the size of the fixing groove 3 and held at a desired position by contacting with the inclined surfaces 7, there still remains an interstice below the optical fiber 9A. Reference numeral 19 denotes a pair of the contacting positions between the optical fiber 9A and the inclined surfaces 7. Thus, if a minute dust particle or fragment is dropped in the fixing groove 3, the minute dust particle or fragment invades in the interstice below the optical fiber 9A but can hardly contact with the optical fiber 9A.

[0041] Fig. 7(b) shows a round bottom 18 in the fixing groove 17. If the optical fiber 9A is held at a desired position by contacting with the inclined surfaces 7, the interstice below the optical fiber 9A has a small gap from the bottom. Thus, if a minute dust particle or fragment 16 is dropped in the fixing groove 17, it invades in the interstice below the optical fiber 9A and easily contact with the optical fiber 9A. As a result, the optical fiber 9A contacts insufficiently with an inclined surface 7 and is likely floated at the position 20.

[0042] When the substrate is formed by the press forming method as described above, the planar shape of the fixing grooves can freely be changed different from the case of forming the fixing grooves by the grinding operation. For example, curved fixing grooves or bent fixing grooves viewed in plan view, which heretofore difficult to prepare, can be prepared. Substrates produced by such preparation methods will be explained below in sequence.

[0043] In the present invention the fixing groove may have a curved portion viewed in plan view.

[0044] Here, the curved portion in the substrate may be one or at least two. Fig. 8(a) is a plan view of an optical fiber-fixing substrate 22 of an embodiment of the second aspect of the present invention, and Fig. 8(b) is a cross-sectional view of an example of the fixing groove. On the main body 21 of the substrate is formed an archedly curved fixing groove 23. The ridge 4A and the bottom 5 have the same forms as those of Fig. 2. According to such a substrate, an optical fiber may correctly be positioned by receiving the optical fiber in the V groove.

[0045] The inventors tried to produce the substrate having the fixing groove of such a planar shape by a publicly known method, but could not produce a substrate which can sufficiently correctly position an optical fiber by such a known method. For instance, when forming a fixing groove 50 which is curved at right angle from an edge 50a to another edge 50b in the main body 21 of the substrate 49 by a grinding method as shown in Fig. 9(a), the grinding wheel has to be moved in a lateral direction and the width of the fixing groove 50 is increased during the moving process, so that the fixing groove 50 has a larger width at the edge 50b than at the edge 50a. As a result, the optical fiber can not be fixed at a desired position.

[0046] Meanwhile, when the substrate is produced by etching of a silicon substrate, the silicon substrate 21 has anisotropic property of crystal orientation in a plane between the x direction and the y direction as shown in Fig. 9(b), so that steps 53, 54 are formed during the gradual change of the direction of the fixing groove 52. As a result, the optical fiber in the fixing groove 52 is hardly positioned at a desired position resulting in a poor reliability.

[0047] In contrast, when the substrate is produced by a press forming method, a mold having a desired planar form can easily be prepared by electrical discharge machining.

[0048] In the second aspect of the present invention, an optical fiber having the same planar shape may be received and fixed in the fixing groove in a stress free state from the inclined surfaces of the fixing groove. For that purpose, an optical fiber is preliminarily separately prepared having substantially the same planar shape with that of the fixing groove, and received in the fixing groove.

[0049] In another embodiment, in an optical device which is a coupling device for coupling the respective optical fibers of a first optical fiber group to the respective optical fibers of a second optical fiber group, the spacing of the respective optical fibers of the first group is different from the spacing of the respective optical fibers of the second group, and the optioal fiber-fixing substrate has the above described curved portion, the substrate having fixing grooves respectively formed corresponding to the optical fibers among the first group and the optical fibers among the second group, one end of the respective fixing groove being formed at a position corresponding to the respective optical fiber of the first group, the other end of the respective fixing groove being formed at a position corresponding to the respective optical fiber of the second group, the optical fibers among the first group and the optical fibers among the second group being received and fixed in the fixing grooves, and the optical fibers among the first group and the optical fibers among the second group being connected to allow communication of light beams therethrough in either directions.

[0050] The above embodiment is applicable to a coupling device for coupling a respective optical guide wave and a respective optical fiber belonging to optical fiber groups, when the spacing of the respective optical fiber in an optical fiber group consisting of a plural number of optical fibers is different from the spacing of the respective optical guide wave in an optical guide wave substrate having a plural number of optical guide waves.

[0051] Fig. 10(a) is a plan view of an optical device

showing an example of this embodiment, Fig. 10(b) is a plan view of an optical device showing another example of this embodiment, and Fig. 10(c) is a side view of the optical device shown in Fig. 10(b). In Fig. 10(a), the optical fibers 59A, 59B of the first optical fiber group are positioned to oppose the left end surface 57a of the substrate 57 and accommodated in a single coating 55 and the spacing d_1 of the optical fibers 59A, 59B is relatively small. In contrast, the optical fibers 59c of the second optical fiber group are positioned to oppose the right end surface 57b of the substrate 57 and accommodated in a respective coating 56 and the spacing d_2 of the respective optical fiber 59C is relatively large. In the left portion of the substrate 57 are formed two rows of the fixing grooves 58A and two rows of the fixing grooves 58B. In the right portion of the substrate 57 are formed fixing grooves 60. The fixing grooves 58A, 58B and the fixing grooves 60 are continuously formed, respectively. The fixing grooves 58A, 58B have respectively a straight portion 58a, an outwardly curved portion 58b, a short straight portion 58c, an inwardly curved portion 58d, and a straight portion 58e, and the straight portion 58e is continuously formed with the fixing groove 60 at the connecting line.

[0052] In the curved portion 58A are accommodated outward optical fibers 59A, while in the curved portion 59B are accommodated inward optical fibers 59C. The respective optical fibers 59A, 59B and the respective optical fiber 59C are coupled to each other. The coupling is effected preferably by the mechanical splice method which is described in NTT Study Feasibility Report Vol. 33, No. 3, (1984), p. 588 etc.

[0053] In the fixing substrate shown in Figs. 10(b) and 10(c), the substrate 57 and the optical fiber-holding substrate 62 are formed as integral one thereby to further proceed the integration of the optical coupling device. In the upper surface of the substrate 62 are formed grooves 62c for receiving the respective coating 56 of the respective optical fiber. The left end surface 57a of the substrate 57 is joined to an end surface 116a of an optical guide wave substrate 116 which has a plural rows of optical guide waves 117A, 117B formed thereon. In this embodiment, the spacing of the optical guide waves is d_1. The respective optical fibers 110A, 110B are respectively accommodated in the coating 56 and the spacing d_2 thereof is relatively larger than d_1.

[0054] In the fixing grooves 58A, 60 are accommodated the outward optical fibers 110A, while, in the fixing grooves 58B, 60 are accommodated the inner optical fibers 110B. The respective optical fibers 110A, 110B are fixed in the fixing grooves by means of an adhesive agent, the end surface 57a of the fixing substrate 57 is optically polished and the polished end surface 57a is optically coupled to the respective optical guide wave. At the time, the outerward optical fiber 110A is optically coupled to a corresponding optical guide wave 117A, and the inward optical fiber 110B is optically coupled to a corresponding optical guide wave 117B. In the drawings, the reference numeral 118 denotes a group of optical guide waves.

[0055] In Figs. 10(a), 10(b), in order to receive the respective optical fiber in a curved fixing groove, preferably a straight optical fiber is sequentially bent and received in a curved fixing groove along the inclined surfaces of the fixing groove. In such a case, the fixing grooves 58A, 58B are smoothly curved, so that there is no afraid that the stresses are concentrated to a portion of the optical fiber in the fixing groove to break off the optical fiber.

[0056] In the embodiment shown in Figs. 10(a) and 10(b), the coating 56 of the optical fiber may usually have a diameter of 0.9 mm. In such a case, the spacing of the fixing grooves 60 is 0.9 mm. The spacing of the tape fibers 59A, 59B or the spacing of the optical guide wave is 0.25 mm, for example, so that the spacing of the fixing grooves 58a is set to 0.25 mm.

[0057] In another embodiment, the optical fiber-fixing substrate is formed by a press forming method and comprises the fixing groove for receiving and positioning an optical fiber which has at least one end portion formed in the substrate viewed in plan view, and the end portion having a end surface which is formed perpendicular to the main surface of the substrate.

[0058] Fig. 11(a) is a plan view of an optical fiber-fixing substrate 40 showing such an embodiment of the present invention, and Fig. 11(b) is a side view thereof. The ridges 44, 44A, the tops 4, 4A and the bottom 5 of the fixing grooves 3 are the same as those of Fig. 2. However, though the fixing grooves 3 are formed substantially parallel to each other to extend from one end surface 2a to a direction of the other end surface 2b, the fixing grooves 3 are terminated at substantially the central portion of the main body 2 of the substrate 40.

[0059] The end surface 6 of the fixing groove 3 in the substrate is substantially a vertical flat surface relative to the main surface of the substrate 40, as shown in Fig. 12(a). If the fixing grooves were formed by the above described press forming method, the angle between the end surface 6 and the main surface of the substrate could be made to 90±0.2 degree. As a result, if the end surface 65a of the optical fiber 65 is made as a vertical surface, the end surface 65a of the optical fiber 65 can be contacted and positioned to the end surface 6.

[0060] In the present invention, an optical guide wave 63 can be formed continuously particularly to the end surface 6 of the fixing groove. By such an arrangement, the optical fiber 65 can automatically optically be coupled to the optical guide wave 63, if the end surface 65a of the optical fiber 65 is contacted with the end surface 6 by positioning the geometrical center of the optical fiber received in the fixing groove and the core of the optical guide wave 63 in x, y directions. For example, such an optical guide wave can be prepared by forming the substrate 64 from an ion exchanged glass and forming the optical guide wave 63 by an ion exchange method.

[0061] In case if the fixing groove was formed by a

grinding method, the end surface 68 of the fixing groove assumes a curved shape, as shown in Fig. 12(b), which in a cross-sectional view has a curvature of radius of usually 20 mm or more depending on the diameter'of the grinding wheel. Therefore, the above described contacting and positioning of the end surface of the optical fiber to the end surface of the fixing groove can not be performed.

[0062] In case if the fixing groove was formed by etching of a silicon substrate, an inclined surface 71 is formed at the end surface of the fixing groove as shown in Fig. 12(c). This is because the etching of the silicon substrate 69 is performed by an anisotropic etching. Usually, the inclined surface 71 is formed having an angle of 54.73° relative to the main surface of the substrate. As a result, a gap is necessarily formed between the end surface 65a of the substrate 65 and the end surface 71 of the fixing groove. In order to remove the gap, the end surface 65b of the substrate 65 has to be provided with the same inclination angle as described above, and the inclined surface 65b and the end surface 71 have to be intimately contacted to each .other without a gap therebetween, as shown in Fig. 12(c). By this arrangement, the optical fiber 65 and the optical guide wave 70 can be contacted to each other without an intervening gap.

[0063] However, if such an optical connecting method is adopted, the direction of the rotation around the central axis of the optical fiber must be exactly adjusted between the end surface 65b of the optical fiber 65 and the end surface 71 of the fixing groove, in case when the optical fiber is inserted in the fixing groove and optically connected to the optical guide wave. However, the positioning of such an optical fiber 65 which is rotatable by 360° in the direction of the rotation is a difficult operation and becomes a cause of increasement of the cost.

[0064] In the optical device 72 shown in Fig. 13, four rows, for example, of the optical fibers 76 existing at an end surface 72a of the device 72 are received respectively in the above described groove, and the vertical end surfaces of the respective optical fiber 76 are contacted to the end surface 6 of the fixing groove which is vertical to the main surface of the substrate to decide their position. One row, for example, of the optical fiber 76 existing at the other end surface 72b of the device 72 is received in the above described groove, and the vertical end surface of the optical fiber 76 is contacted to the end surface 6 of the fixing groove which is vertical to the main surface of the substrate to decide its position. The end surfaces of the optical fibers 76 are optically connected to the branched portion 73a or the straight portion 73c of the optical guide wave 73 in the substrate, as shown in Fig. 13. The branched portion 73a and the straight portion 73c are united at the branching point 73b.

[0065] When forming an ion exchanged optical guide wave, usually, a glass substrate is ion exchanged at the surface to prepare an optical guide wave of a depth of around 10 μm. Therefore, the center of the optical guide wave exists in a depth of around 5 μm from the surface. Hence, the size and the shape of the fixing groove are designed such that the center of the optical fiber received in the fixing groove is coincident with the center of the optical guide wave. By designing the fixing groove in such a fashion, the centering of the substrate in the depth direction can be mechanically realized.

[0066] When coupling the optical fiber and the optical guide wave in this way, the end surface of the fixing groove have to be polished to a mirror surface to permit efficient permeation of light beams therethrough.
In the present invention, the end surface of the fixing groove can be polished to a mirror surface by polishing that surface of the press mold which corresponds to the end surface of the fixing groove to a mirror surface. Particularly preferably, an average surface roughness Ra of the end surface of the fixing groove can be made to a small value of 10 nm or less.

[0067] An optical guide wave can be formed in the surface of the glass substrate also by a flame deposition method.

[0068] In a further embodiment of the third aspect, the optical fibers in the fixing groove can be coupled to optical elements. According to this embodiment, the above described fixing groove can be formed at any portion viewed in plan view of the optical fiber-fixing substrate. Namely, an end surface of the fixing groove can be provided at a desired point of the substrate and the other end surface of the fixing groove can be provided at a position opposing the optical elements. By receiving and fixing the optical fibers in this fixing groove, the optical fibers can be optically coupled to the optical elements on the substrate without centering the optical fibers.

[0069] As such optical elements, luminescent element and light receiving element are particularly useful. Fig. 14 is a perspective view of an embodiment of such an optical device to which the present invention is applied. A fixing groove having the same shape as that shown in Fig. 2 is provided in an optical device 74 to face an end surface 74a of the optical device 74. An end surface of the optical fiber 77 received in the fixing groove is contacted to an end surface 6 of the fixing groove. A luminescent interface of a luminescent diode 79 is positioned at a position opposing the end surface 6. Between the luminescent interface of the luminescent diode 79 and the end surface of the optical fiber 77 (namely, an end surface of the fixing groove) is provided a desired gap portion 80, because the luminescent diode is likely deteriorated if the luminescent interface is directly contacted to the end surface of the optical fiber 77. The reference numeral 78 denotes an electrode for controlling the luminescent diode 79.

[0070] The luminescent diode emits light beams at a height of, for example, 10 μm viewed from the bottom of the luminescent diode (a surface of the substrate). Therefore, in such a case, the size and the shape of the fixing groove are designed such that the center of the

optical fiber received in the fixing groove is coincident with the position of the luminescence of the luminescent diode.

[0071] The present invention is applicable to optical integrated elements, such as, described in SASAKI Masami et al "Hybrid Integrated Mounting of Semiconductor Laser Array Module using Si Substrate" reported in Communicationology Technical Report EDM94-29, CPM94-43, OPE94-38(1994-08); "Hybrid-technique couples laser array to fibers" reported in LASER FOCUS WORLD May 1991 p217; and NTT Optoelectronics Research Center, YAMADA Yasufumi's report "Hybrid Optointegrating Technology using Quartz-series Planer Optical Wave Circuits" (The Third Photoelectronics Information Treatment Research Members Document).

[0072] In the present invention, the fixing groove in the substrate may be provided with at the both ends respectively the aforedescribed end surface 6 which is vertical to the main surface of the substrate. The assembly may be severed to produce a substrate which has a fixing groove opened at one end and which has the end surface 6 at the other end.

[0073] In another embodiment an optical device has an optical fiber-fixing substrate produced by a press forming method, comprising fixing grooves for receiving and positioning light beam transmitting members, a first protrusion having a first fixing groove formed therein, a second protrusion having a second fixing groove formed therein, and a coupling portion coupling the first protrusion and the second protrusion, the first fixing groove having a higher height viewed from the surface of the coupling portion than the height of the second fixing groove, and the light beam transmitting member received and fixed in the first fixing groove and the light beam transmitting member received and fixed in the second fixing groove being optically coupled to each other.

[0074] In such an embodiment, if an optical element is fixed at the coupling portion, the height of a position of an incident light beam in the optical element viewed from the surface of the coupling portion may be different from the height of a position of an emitted light beam, and the light beam transmitting member received and fixed in the first fixing groove and the light beam transmitting member received and fixed in the second fixing groove may be optically coupled to each other through the optical element. As such an optical element, any optical element may be used having different heights of positions of an incident light beam and an emitted light beam, and an optical isolator is particularly preferable.

[0075] Heretofore, such arrangements are known wherein optical fibers are disposed to oppose in V grooves of optical fiber-fixing substrates, and a wave length filter or an optical isolator is disposed between the opposing substrates, as reported by "O plus E." January, 1991, p124-125, and CHUZENZI Tomihiro et al "Optical Fiber Integrated Type Biased Wave Non-dependent Isolator" Electron Information Communication Society, Autumn Meeting C-229 (1992). However, such arrangements have still large optical losses and insufficient isolation properties. Therefore, in a system adopted in commercially sold optical isolators, two collimators are opposingly disposed and an optical isolator element is disposed between the opposing two collimators, as reported by NOUCHI Tomohiko et al "Compact All Resin-free Biased Wave Non-dependent Optical Isolator" Electron Information Communication Society, Autumn Meeting C-216 (1993), and HIRAI Shigeru et al "Properties of Biased Wave Surface Non-dependent Type Optical Isolator" Electron Information Communication Society, Autumn Meeting C-230 (1992). Collimators are usually used in PC connectors and are elements prepared by preliminarily incorporating lenses in an optical system assembled by incorporating optical fibers in ferrules.

[0076] However, in an optical isolator of such a system, when the positioning of the collimators is performed, the alignment of the two axes, namely, X axis and Y axis, has to be performed as well as the alignment in the rotational directions of θX and θY axes, and these alignments require much labor and time.

[0077] The present invention provides, in an optical element, particularly optical isolator, wherein the optical axis is changed due to a shift of the optical fiber in the interior, a method of directly collimating optical axes by optical fibers held in an optical fiber-fixing substrate. By this method, the conventional cumbersome problem of adjusting the X axis, Y axis, θX axis and θY axis is not necessary and can be dispensed with.

[0078] Fig. 15(a) is a perspective view of an optical fiber-fixing substrate 24 which is used in an embodiment of the present invention and Fig. 15(b) is a plan view of the optical fiber-fixing substrate 24. The substrate 24 is provided with a first protrusion 25 positioned at a relatively higher level, a second protrusion 26 positioned at a relatively lower level viewed from the surface of a coupling portion 27 than the first protrusion 25, and a coupling portion 27 connecting the first protrusion 25 and the second protrusion 26.

The protrusions 25, 26 have respectively a first fixing groove 3A and a second fixing groove 3B. The shape per se of the fixing grooves are the same as those shown in Fig. 2. Both the fixing groove 3A in the first protrusion 25 and the fixing groove 3B in the second protrusion 26 extend straightly, and the fixing grooves 3A and 3B are existent on a same line when viewed in a plan view.

[0079] According to the press forming method, the protrusions 25, 26 positioned at different levels of height and the coupling portion 27 can simultaneously be formed in a single pressing process. Such a processing can hardly be effected by a grinding process or an etching process.

[0080] In the fixing grooves 3A and 3B in the first and second protrusions are respectively received and positioned an optical fiber. At that time, if an optical element, such as, a birefringent plate or an optical isolator having

different heights of positions of an incident light beam and an emitted light beam, is arranged on the coupling portion 27, the optical axis of the optical fiber in the fixing grooves 3A and that of the optical fiber in the fixing grooves 3B does not coincident but displaced. The distance or the step difference between the optical axes of the fixing grooves 3A and 3B is adjusted, considering the displacement. In case when the optical fiber has an inclined end surface, the optical axes of the respective optical fiber are similarly displaced between the fixing grooves 3A and 3B, so that the distance or the step difference between the optical axes of the fixing grooves 3A and 3B is adjusted.

[0081] As illustrated in the drawing, an optical fiber 65A is received and fixed in the fixing groove 3A of the first protrusion 25, and an optical fiber 65B is received and fixed in the fixing groove 3B of the second protrusion 26 to perform the positioning, as shown in Fig. 16(a), for example. An optical isolator 90 is disposed on the surface 91 of the coupling portion 27 between the end surface 25a of the first protrusion 25 and the end surface 26a of the first protrusion 26, and lenses 92A, 92B are disposed on the both sides of the optical isolator 90. At this state, though the optical axes 93 and 94 at the both sides of the optical isolator 90 have a displacement, the step difference between the optical axes 93 and 94 is adjusted by adjusting the step difference between the fixing grooves 3A and 3B.

[0082] Also when the optical fiber has an inclined end surface, the optical axis of the optical fiber in the fixing groove 3A has a displacement from that of the optical fiber in the fixing groove 3B in the same manner as described above. For example, as illustrated in Fig. 16(b), an optical fiber-fixing substrate 95 is provided with a first protrusion 25A positioned at a relatively higher level, a second protrusion 26A positioned at a relatively lower level viewed from the surface of a coupling portion 27 than the first protrusion 25A, and a coupling portion 27 connecting the first protrusion 25A and the second protrusion 26A. The protrusion 25A has an inclined surface 97 relative to the vertical surface at the inner side facing the coupling portion, and the protrusion 26A has also an inclined surface 98 relative to the vertical surface at the inner side facing the coupling portion. Simultaneously, the optical fibers 65A, 65B have inclined end surfaces 99 relative to the vertical surface. The inclination of the end surfaces 99 of the respective optical fibers 65A, 65B is to prevent reabsorption of the reflected light beam into the optical fibers. Both the fixing groove 3A in the first protrusion 25A and the fixing groove 3B in the second protrusion 26A extend straightly, and the fixing grooves 3A and 3B are existent on a same line when viewed in a plan view.

[0083] In the fixing grooves 3A and 3B are respectively received, fixed and positioned optical fibers 65A and 65B. At this state, though the optical axis 100 connecting the optical fiber 65A in the fixing groove 3A and the optical fiber 65B in the fixing grooves 3B has an inclination to the horizontal surface, the emitted light beam emitted from the end surface of the optical fiber 65A can be adjusted to incident in the optical fiber 65B by adjusting the step difference between the fixing grooves 3A and 3B.

[0084] In addition, the above described optical device can be afforded with a function to hold the coating of the optical fibers. By affording such a function, attachment of the optical fibers to the optical device can further be facilitated. Also, by disposing an optical element in the receiving hole at the surface of the coupling portion to allow the positioning of the optical element, a relative position of the optical element to the respective optical fiber, particularly, a distance between the optical element and the optical fiber, and the angle of the optical element, can easily and correctly be decided.

[0085] For example, in the optical device as shown in Fig. 16(c), a substrate 112 is provided with a first protrusion 102A positioned at a relatively higher level, a second protrusion 102B positioned at a relatively lower level viewed from the surface of a coupling portion 27 than the first protrusion 102A, and a coupling portion 27 connecting the first protrusion 102A and the second protrusion 102B. The protrusions 102A and 102B have respectively a first fixing groove 3A and a second fixing groove 3B formed therein. An optical element 90 is inserted and fixed in a receiving hole 104 formed in the coupling portion 27. By adjusting the depth and the planer position of the receiving hole 104, the optical fiber in the fixing groove 3A and the optical fiber in the fixing groove 3B can be optically coupled automatically.

[0086] The coating 56 of the optical fiber is received and fixed in a V groove 101A for positioning arranged at an end portion of the first protrusion 102A. The coating 56 of the optical fiber is received and fixed in a V groove 101B for positioning arranged at an end portion of the second protrusion 102B.

[0087] The aforedescribed displacement of the optical axes, namely, the displacement between the optical axis of the optical fiber held in the first protrusion and the optical axis of the optical fiber held in the second protrusion is not particularly limited, however, it is usually around 50-150 μm.

[0088] In the optical device shown in Fig. 17, the substrate 115 is provided with a first protrusion 102C positioned at a relatively higher level, a second protrusion 102D positioned at a relatively lower level viewed from the surface of a coupling portion 27 than the first protrusion 102C, and a coupling portion 27 connecting the first protrusion 102C and the second protrusion 102D.

[0089] The protrusions 102C and 102D have respectively a first portion 84A, 84B having the fixing groove of a relatively large cross-sectional size and a second portion 85A, 85B having the fixing groove of a relatively small cross-sectional size.

[0090] End surfaces 86A, 86B of the first portions 84A, 84B have respectively an inclined surface relative to the main surface of the substrate 115 between the

first portions 84A, 84B and the second portions 85A, 85B. In the first portions 84A, 84B are received and fixed passive light beam transmitting members 87A, 87B of relatively large diameters. In the second portions 85A, 85B are received and fixed the optical fibers 65A, 65B of relatively small diameters. End surfaces 87a of the light beam transmitting members 87A, 87B are contacted with the end surfaces 86A, 86B and positioned thereby. As a result, the end surfaces 65a of the optical fibers 65A, 65B are contacted with the end surface 87a of the light beam transmitting members 87A, 87B without a gap therebetween.

[0091] As the light beam transmitting members 87A, 87B, may be particularly exemplified lenses (GRIN lens, ball lens, etc.), optical fibers of relatively large diameters.

[0092] In the V groove 101A for positioning arranged at the end of the first protrusion 102C is received and fixed the coating 56 of the optical fiber. In the V groove 101B for positioning arranged at the end of the second protrusion 102D is received and fixed the coating 56 of another optical fiber.

[0093] In the embodiment shown in Fig. 17, the diameter of the cross-section of the fixing grooves 85A, 85B for fixing the optical fibers is 0.125 mm, for example, and the diameter of the cross-section of the fixing grooves 84A, 84B for fixing the lenses is 1 mm, for example.

[0094] Fig. 18 is a side view of an optical fiber-fixing substrate 105, Fig. 18(b) is a front view of the substrate 105 viewed from an end side thereof, and Fig. 18(c) is a front view of the substrate 105 viewed form the other end side opposing the Fig. 18(b).

[0095] In a pair of the end surfaces of the substrate 106 are formed optical fiber-fixing grooves 109. The grooves 109 are V grooves in this embodiment. The size of the cross-section of the fixing grooves 109 is small at the end 107 and large at the end 108 and gradually increases from the end 107 towards the end 108 between the two ends. The optical fibers 65 are received and fixed along the bottom of the fixing grooves 109.

[0096] Next, there is described a preferred material constituting the optical fiber-fixing substrate.

[0097] The inventors have found, in the process of producing the optical fiber-fixing substrates of various shapes by using the press forming method, that the optical fiber-fixing substrates of a very high precision, particularly a precision of 1.0 μm or less, can be obtained if the following material is used.

[0098] Namely, the material preferably used has an average particle diameter of crystal grains constituting the glass ceramics of 1.0 μm or less, the main crystal layer being composed of lithium disilicate ($Li_2O{\cdot}2SiO_2$) phase and β-spodumen ($Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$) or β-spodumen solid solution phase, and the amount of than crystal phase of SiO_2 composition being not more than 2 wt%.

[0099] Here, the expression "a crystal phase of SiO_2 composition" includes quartz, crystoballite and crystals of other structures. However, hereinafter in the present specification, among "a crystal phase of SiO_2 composition" those crystal phases having crystal structures other than quartz and crystoballite will be called by an abbreviated name of "SiO_2 crystal phase".

[0100] The inventors at first studied various glass ceramics and, as a result, succeeded in almost eliminating the Li_2O-SiO_2 phase and the crystal phase of SiO_2 composition to convert them to $Li_2O{\cdot}2SiO_2$ phase and β-spodumen ($Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$) or β-spodumen solid solution phase, by limiting the material proportion ratio and crystallizing the material under the later described temperature condition. The glass ceramics has the main crystal phase consisting of lithium disilicate phase and β-spodumen or β-spodumen solid solution phase, and the crystal phase of SiO_2 composition of not more than 2 wt%.

[0101] By using such a glass ceramics, the above described defect or break-off of the optical fiber-fixing substrates can effectively be prevented. Particularly, the connector described in Japanese Patent Application No. 4-17,752 having a function of detaching has the problem of the defect, etc., if it is made of a usual glass ceramics, so that the optical fiber-fixing substrate made of the aforedescribed specific glass ceramics is particularly preferable for such a connector. Also, the optical fiber-fixing substrate of a very high precision could be produced by the press forming method.

[0102] The composition and the production method of the glass ceramics will be explained further. Regarding the glass ceramics, the crystal phase of SiO_2 composition has to be made to not more than 2 wt% and the proportional ratio of the lithium disilicate phase to β-spodumen or β-spodumen solid solution phase has to be made to the later described given ratio.

[0103] Concretely explaining, when producing the optical fiber-fixing substrate, a raw glass of a composition of 65-85 wt% of SiO_2, 8-15 wt% of Li_2O, 5-8 wt% of Al_2O_3 and 1-5 wt% of P_2O_5, preferably a composition of 75-80 wt% of SiO_2, 9-14 wt% of Li_2O, 5-8 wt% of Al_2O_3 and 1-3 wt% of P_2O_5, is heated at a heating temperature of 820-950°C to prepare the glass ceramics.

[0104] Al_2O_3 is a necessary component for forming the β-spodumen or β-spodumen solid solution phase and also necessary for improving the stability of the crystal phase of the glass ceramics. If it if less than 5 wt%, β-spodumen is not formed in the crystal phase and the amount of the crystal phase of SiO_2 composition exceeds 2 wt%.

[0105] SiO_2 is an indispensable fundamental component for obtaining the crystal phases of lithium disilicate phase, etc. If it is less than 65 wt%, the desired crystal phases can hardly be precipitated, while if it exceeds 85 wt%, the melting of the glass ceramics becomes difficult.

[0106] As a result of the heat treatment of the aforedescribed raw glass, the inventors have found out that a temperature of 820-950°C has to be adopted for the crystallization of the glass. Namely, heretofore, crystallization of Li_2O-SiO_2-Al_2O_3 series glass at a tempera-

ture in a broad range of 700-950°C has been known. However, in the present invention, by crystallizing the raw glass of the above composition, 30-60 wt% of lithium disilicate phase, 1-25 wt% of β-spodumen and β-spodumen solid solution phase, the proportion of the phases being not less than 1.0, should preferably be prepared. For preparing the substrate made of a glass ceramics of such a specific composition, a crystallization temperature of 820-950°C has to be adopted for the raw glass.

[0107] In addition, the inventors have found out that, in order to obtain the highest strength of the glass ceramics, a crystallization temperature of 820-920°C is preferable, and a crystallization temperature of 820-900°C is more preferable.

[0108] Explaining further, when heat treating the raw glass, if the heat treating temperature or crystallization temperature is around 700-750°C, the $Li_2O{\cdot}SiO_2$ phase and the $Li_2O{\cdot}2SiO_2$ phase are formed in an amount of 30-50% and a some amount of the crystal phase of SiO_2 composition is formed. At that time, with the increase of the treating temperature the $Li_2O{\cdot}SiO_2$ phase and the $Li_2O{\cdot}2SiO_2$ phase are increased simultaneously. At this stage, the substrate is weak in strength and can not be used.

[0109] If the heat treating temperature is increased to a temperature of around 800°C, the $Li_2O{\cdot}SiO_2$ phase is rapidly disappeared and $Li_2O{\cdot}2SiO_2$ phase and the crystal phase of SiO_2 composition are rapidly increased.

[0110] However, if the heat treating temperature is increased to a temperature of 820°C, the crystal phase of SiO_2 composition is disappeared, while the $Li_2O{\cdot}2SiO_2$ phase is increased. Also, it was found out that the β-spodumen phase is rapidly increased simultaneously. This means that, at this region of temperature, the crystallization of the Al_2O_3 component progressed for the first time to form the β-spodumen phase ($Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$) or β-spodumen solid solution. At the stage before the formation of $Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$ composition, the proportion of Li_2O, Al_2O_3 and SiO_2 in the crystal phase does not exactly reach to the proportion of the $Li_2O{\cdot}Al_2O_3{\cdot}4SiO_2$ composition, though it has a similar crystal structure, so that it is called "β-spodumen solid solution".

[0111] In the heat treating temperature range of 820-920°C, the lithium disilicate phase and β-spodumen or β-spodumen solid solution phase are gradually increased with the increase of the treating temperature. In the temperature range, the average crystal grain diameter is not more than 1.0 μm and the strength of the substrate can be maintained extremely high. However, if the heat treating temperature exceeds 950°C, crystal phases are not largely changed but the average crystal grain diameter is increased to exceed 1.0 μm so that a tendency was observed of decreasing the strength of the substrate.

[0112] The inventors have found out that a problem is arisen in the substrate of the present invention if the β-spodumen phase is excessively increased as compared with the original lithium disilicate phase. That is, the mechanical strength of the substrate was decreased if the formation of the crystal grains of the β-spodumen phase is so progressed to decrease the weight ratio of the lithium disilicate phase/(the total amount of the β-spodumen phase plus β-spodumen solid solution) to less than 1.0.

[0113] From the above reason, it was found that the above described weight ratio should preferably be not less than 1.0. It was also found that a more preferable mechanical strength of the substrate can be obtained if the above described weight ratio is not less than 1.3.

[0114] If the Al_2O_3 component in the raw glass exceeds 8 wt%, the crystal grains of the β-spodumen phase is so excessively formed that the strength of the substrate was decreased. Therefore, the amount of the Al_2O_3 component in the raw glass should not exceed 8 wt%.

[0115] When heating the raw glass in the above producing method, preferably a temperature raising rate of 50-300°C/hr is maintained in a temperature region of at least 500°C to proceed the formation of the crystal nuclei. Also, the heating is preferably effected in a temperature range of at least 500-580°C for 1-4 hrs to proceed the formation of the crystal nuclei.

[0116] Components other than that described above may be contained in the glass ceramics used for the substrate. For example, as a nucleating agent other than the P_2O_5, a metal oxide, such as, TiO_2, ZrO_2 or SnO_2 or a metal, such as, platinum, or a metal fluoride may be used alone or in admixture of at least two.

[0117] K_2O may be contained in the glass ceramics in an amount of 0-7 wt%. This component has effects of lowering the melting and forming temperature of the glass and preventing the devitrification of the glass at the time of forming the glass. In order to exhibit such functions, the glass preferably contain not less than 2 wt% of the K_2O component. If the content of the K_2O component exceeds 7 wt%, the strength of the glass ceramics tends to decrease.

[0118] Either one of As_2O_3 and Sb_2O_3 or the both may be contained in the glass ceramics in a total amount of 0-2 wt%. These components serve as a clarifier in melting the glass.

[0119] In addition, 0-3 wt% of B_2O_3 component, 0-3 wt% of CaO component, 0-3 wt% of SrO component and 0-3 wt% of BaO component may be contained in the glass ceramics. Preferably, MgO component is substantially not contained in the glass ceramics.

[0120] In producing the raw glass, raw materials containing the above components are mixed to give the aforedescribed weight ratio and the mixture is melted by heating. As such raw materials, oxides, carbonates, nitrates, phosphates and hydroxides of the respective metal atoms may be exemplified. As the atmosphere of heat treating the raw glass and crystallizing the glass, aerial atmosphere or an inert atmosphere, etc. may be

selected.

[0121] The optical fiber-fixing substrate made of the material is similarly applicable to the optical fiber-fixing substrate of a different form from the aforedescribed optical fiber-fixing substrates explained with reference to Figs. 2-6.

[0122] The inventors have found out that the following (1)-(4) materials are particularly superior as the material for constituting the optical fiber.

(1) BK-7 optical glass

[0123] This glass has a high ultra violet ray (UV ray) permeating property and a coefficient of thermal expansion (CTE) of around 70×10^{-7}/°C, so that the glass can make small the difference of thermal expansion between the optical fiber and the optical guide wave on the substrate made of $LiNbO_3$. If the glass is used for fixing a ball lens or the like BK-7 article, the glass is most satisfactory because the glass is made of the same material as the BK-7 article. When the optical fiber and the optical fiber-fixing substrate are adhered to each other by means of an UV ray-curable resin adhesive after the optical coupling thereof, the material of the optical fiber-fixing substrate is requested to have a high UV ray permeability. For that purpose, the BK-7 glass is quite suitable because it has a high permeability of not less than 90% at the wave length of λ=360 nm.

[0124] When the optical fiber-fixing substrate is coupled to an X-cut $LiNbO_3$ optical guide wave, the substrate having the X-cut $LiNbO_3$ optical guide wave has a CTE of 150×10^{-7}/°C in one direction and a CTE of 40×10^{-7}/°C in another direction. Therefore, if the matching of the CTEs of the two directions is considered, the material constituting the optical fiber-fixing substrate should preferably have a CTE of 85×10^{-7}/°C. The BK-7 glass has such a level of CTE.

[0125] Usually, the BK-7 glass is used as the material of ball lenses etc. and the use of the BK-7 glass as the material of the optical fiber-fixing substrate removes the difference of CTE between the ball lenses etc. and the optical fiber-fixing substrate.

(2) Borosilicate glass

[0126] Borosilicate glass has a low CTE of $\alpha=32\times10^{-7}$/°C which is a very low CTE among the usually commercially available glasses. This glass can produce the optical fiber-fixing substrate of a low expansion without performing the crystallization treatment etc. Also, this glass allows the use of the UV ray-curable resin in the similar manner as described above in that it has a high UV ray permeability.

(3) Soda lime glass

[0127] Soda lime glass, if impregnated in a KNO_3 solution at 480°C, can achieve an improved strength by ion exchange of Na^+ with K^+ in a range of 30 µm from the surface.

(4) Ion exchanged glass

[0128] If the optical fiber-fixing substrate using this material is used, an optical guide wave can directly be formed on the substrate to allow direct coupling of the optical guide wave to the optical fiber.

[0129] Hereinafter, more concrete experimental results will be explained. According to the aforedescribed method, the optical fiber-fixing substrate 1 shown in Fig. 2 and the optical fiber-fixing substrate 45 shown in Fig. 6 were produced by the press forming method. However, an alumina powder of a purity of 99.8% was used as the raw material which was added with 3% of polyvinyl alcohol (PVA) and 1% of polyethylene glycol (PEG) as a binder and granulated by a spray dryer to obtain the material for forming.

[0130] Meanwhile, a mold 37 of a shape shown in Fig. 4 was prepared. At that time, the mold 37 was prepared from a super hard alloy and ground at the surface by a diamond grinding wheel to form the respective fixing groove 38. The material for forming was filled between the mold 37 and the lower mold of a planer shape and press formed under a pressure of 2,000 kg/cm^2. The thus obtained shaped body was fired in an oxidizing atmosphere at 1,600°C to produce an optical fiber-fixing substrate. An optical fiber was received in the respective fixing groove of the substrate and contacted strongly to the ridges of the fixing groove. Afterwards, the neighborhood of the fixing groove was observed.

[0131] Fig. 19 is a photograph of the neighborhood of the fixing groove 3 of the optical fiber-fixing substrate 5 shown in Fig. 6. As clearly apparent, the ridges of the fixing grooves are round and the bottoms are very sharp. The respective ridge existing between the fixing grooves did not have a particular defect or break-off portion. The similar results were obtained regarding the optical fiber-fixing substrate 1 shown in Fig. 2.

[0132] In the meantime, the above material for forming was formed to obtain a formed body of a planer shape which was then fired in an oxidizing atmosphere at 1,600°C to produce an optical fiber-fixing substrate main body of a planer shape. A surface of the substrate main body was ground by a diamond grinding wheel to obtain the substrate 8 shown in Fig. 3. An optical fiber was received in the respective fixing groove 12 of the substrate 8 and contacted strongly to the ridges of the fixing groove 12. Afterwards, the neighborhood of the fixing groove was observed.

[0133] As a result, break-off portions as shown in Fig. 20 were observed at some portions of the substrate. As clearly apparent, the ridges of the fixing grooves are very sharp and the bottoms are round.. It is noted that the break-off portions are formed extending in the direction of from the top of the ridges towards the bottom of the fixing grooves. This is presumably considered that

the break-off portions or cracks where began from around the top portion of the ridges.

[0134] Li_2O-Al_2O_3-SiO_2 series glasses were press formed using the above mold and the shaped bodies were crystallized by the heat treatment to produce the substrates 1, 45 shown in Figs. 2, 6. The substrates were observed in the same manner as described above to obtain the same results as described above.

[0135] As explained in detail in the foregoings, the present invention can prevent the formation of the defect or break-off of the ridges of the fixing grooves when the optical fibers are received in the fixing grooves of the optical fiber-fixing substrates or when the end surfaces of the substrates are polished by grinding.

Claims

1. An optical fiber fixing substrate (1) having at least one fixing groove (3) formed in the substrate for receiving and positioning an optical fiber (9), the or each said groove (3) being defined by one of:

   (i) a pair of adjacent ridges (4) which each separate two such fixing grooves (3),
   (ii) on one side a ridge (4) which separates two such fixing grooves and on the opposite side by a side wall which joins a flat surface of the substrate, and
   (iii) a pair of opposed side walls which each joins a flat surface of the substrate,

   wherein the edge of each said ridge (4) or the edge formed between each said side wall and the flat surface, as viewed in cross-section perpendicular to the longitudinal direction of the groove (3), is rounded with a radius of curvature of not less than 5 µm.

2. The optical fiber fixing substrate of claim 1, wherein the bottom (5) of the or each fixing groove (3) has a curvature of radius of not more than 5 µm as viewed in cross-section perpendicular to the longitudinal direction of the groove.

3. The optical fiber fixing substrate of claim 1 or 2, wherein the substrate is made of a glass or ceramics.

4. The optical fiber fixing substrate of claim 1, wherein the or each fixing groove (3) is formed by press forming.

5. An optical fiber fixing substrate according to claim 3, wherein said fixing groove has a curved portion (23) as viewed in plan view on the substrate.

6. The optical fiber fixing substrate according to claim 5, wherein an optical fiber having the same planar shape as the fixing groove is received and fixed in the fixing groove in such a fashion that the stresses from the inclined surfaces of the fixing groove are not exerted on the optical fiber.

7. An optical device which is a coupling device for coupling the respective optical fibers (59A, 59B) of a second optical fiber group where the spacing of the respective optical fibers of the first group is different from the spacing of the respective optical fibers of the second group, comprising an optical fiber fixing substrate (57) according to claim 6, the substrate (57) having said fixing grooves (58A, 58B, 60) formed therein as spacings corresponding at one end to the optical fibers (59A, 59B) of the first group and at their opposite end to the optical fibers of the second group, the optical fibers of the first group and the optical fibers of the second group being received and fixed in the fixing grooves and being connected to allow communication of light beams therethrough in two directions.

8. An optical device which is a coupling device for coupling the respective optical fibers (110A, 110B) of a group of plural optical fibers to the respective optical waveguides (117A, 117B) of a group of plural optical waveguides where the spacing of the respective optical fibers of the optical fiber group is different from the spacing of the respective optical waveguides ((117A, 117B) comprising an optical fiber fixing substrate according to claim 6, the substrate having fixing grooves (58A, 58B, 60) respectively formed therein corresponding to the respective optical fibers and the respective optical waveguides, one end of the respective fixing grooves being at positions corresponding to the respective optical fibers, the other end of the respective fixing grooves being at positions corresponding to the respective optical waveguides, the respective optical fibers being received and fixed in the fixing grooves and the respective optical fibers and the respective optical waveguides being connected to allow communication of light beams therethrough in two directions.

9. An optical fiber fixing substrate according to claim 1, wherein the fixing groove (3) has an end (6) located within the substrate as seen in plan view on a main surface in which the fixing groove is formed, and the end has an end surface which is perpendicular to said main surface.

10. An optical device, comprising an optical fiber fixing substrate (64) according to claim 1, having an optical waveguide (63) or an optical element formed on the substrate, an optical fiber received and fixed in the fixing groove of the substrate, an end surface of the optical fiber being optically coupled to the optical waveguide (63) or the optical element.

11. An optical fiber fixing substrate according to claim 1, wherein the substrate (24) has a first protrusion wherein a first said fixing groove (3A) is formed, a second protrusion wherein a second said fixing groove (3B) is formed and a connecting portion (27) connecting the first protrusion and the second protrusion, the first fixing groove (3A) being positioned at a greater height above the surface of the connecting portion than the second fixing groove (3B).

12. An optical device, comprising an optical fiber fixing substrate according to claim 11, and an optical fiber (65A) received and fixed in the first fixing groove and an optical fiber (65B) received and fixed in the second fixing groove, the optical fibers (65A, 65B) being optically coupled to each other.

13. An optical device comprising an optical fiber fixing substrate according to claim 11, and an optical element (90) fixed to the connecting portion (27), the height of an incident light beam in the optical element (90) being different from the height of an emitting light beam emitted from the optical element with respect to the surface of the connecting portion, a light beam transmitting member (65A) received and fixed in the first fixing groove, a light beam transmitting member (65B) received and fixed in the second fixing groove, the light beam transmitting members (65A, 65B) being optically coupled to each other through the optical element.

14. An optical device comprising an optical fiber fixing substrate according to claim 11, comprising a light beam transmitting member (65A) received and fixed in the first fixing groove (3A), a light beam transmitting member (65B) received and fixed in the second fixing groove (3B), wherein end surfaces (99) of the light beam transmitting members are inclined to the plane perpendicular to the length direction of the light beam transmitting members (65A, 65B).

15. An optical fiber fixing substrate according to claim 1 formed by press forming, wherein the substrate is made of a glass ceramics, the glass ceramics having an average crystal grain diameter of not more than 1.0 µm, the main crystal phases being lithium disilicate (Li_2O-$2SiO_2$) phase, β-spodumene (Li_2O-Al_2O_3-$4SiO_2$) phase or β-spodumene solid solution phase, and the content of the crystal phases of SiO_2 composition being not more than 2 wt%.

16. A method of producing an optical fiber-fixing substrate according to claim 1, wherein a mold having a shape which corresponds to the fixing groove is prepared, the groove of the mold is prepared by grinding work at that time, and the mold is used to press the material of the substrate.

17. A method of producing an optical fiber fixing substrate according to claim 1, comprising forming the or each groove (3) and then polishing the ridges and/or side walls by grinding such that they have said curvature of radius of not less then 5 µm.

Patentansprüche

1. Substrat (1) zum Befestigen einer optischen Faser mit zumindest einer Befestigungsrille (3), die im Substrat ausgebildet ist, um eine optische Faser (9) aufzunehmen und anzuordnen, wobei die oder jede Rille (3) definiert ist durch eines aus:

   (i) einem Paar benachbarter Rippen (4), die jeweils zwei derartige Befestigungsrillen (3) voneinander trennen,
   (ii) einer Rippe (4) auf einer Seite, die zwei derartige Befestigungsrillen voneinander trennt, und durch eine Seitenwand auf der gegenüberliegenden Seite, die an eine ebene Oberfläche des Substrats anschließt, sowie
   (iii) einem Paar eiriander gegenüberliegender Seitenwände, die jeweils an eine ebene Oberfläche des Substrats anschließen,

   wobei die Kante einer jeden Rippe (4) oder die Kante, die jeweils zwischen der Seitenwand und der ebenen Oberfläche ausgebildet ist, im Querschnitt senkrecht zur Längsrichtung der Rille (3) gesehen, mit einem Krümmungsradius von nicht weniger als 5 µm abgerundet ist.

2. Substrat zum Befestigen einer optischen Faser nach Anspruch 1, worin der Boden (5) der oder einer jeden Befestigungsrille (3) eine Krümmung mit einem Radius von nicht mehr als 5 µm, im Querschnitt senkrecht zur Längsrichtung der Rille gesehen, aufweist.

3. Substrat zum Befestigen einer optischen Faser nach Anspruch 1 oder 2, worin das Substrat aus Glas oder Keramik besteht.

4. Substrat zum Befestigen einer optischen Faser nach Anspruch 1, worin die oder jede Befestigungsrille (3) durch Formpressen gebildet ist.

5. Substrat zum Befestigen einer optischen Faser nach Anspruch 3, worin die Befestigungsrille einen in Draufsicht auf das Substrat gesehen gekrümmten Abschnitt (23) aufweist.

6. Substrat zum Befestigen einer optischen Faser nach Anspruch 5, worin eine optische Faser mit der gleichen planaren Gestalt wie die Befestigungsrille in der Befestigungsrille auf solche Weise aufge-

nommen und befestigt ist, dass die Spannungen von den geneigten Oberflächen der Befestigungsrille nicht auf die optische Faser ausgeübt werden.

7. Optische Vorrichtung, die eine Kopplungsvorrichtung zum Koppeln der jeweiligen optischen Fasern (59A, 59B) einer zweiten Gruppe optischer Fasern ist, wobei sich der Abstand zwischen den jeweiligen optischen Fasern der ersten Gruppe vom Abstand zwischen den jeweiligen optischen Fasern der zweiten Gruppe unterscheidet, umfassend ein Substrat (57) zum Befestigen optischer Fasern nach Anspruch 6, wobei im Substrat (57) die Befestigungsrillen (58A, 58B, 60) mit Abständen ausgebildet sind, die an einem Ende den optischen Fasern (59A, 59B) der ersten Gruppe und an ihrem gegenüberliegenden Ende den optischen Fasern der zweiten Gruppe entsprechen, wobei die optischen Fasern der ersten Gruppe und die optischen Fasern der zweiten Gruppe in den Befestigungsrillen aufgenommen und in diesen befestigt sind, und die verbunden sind, um Nachrichtenverkehr mittels Lichtstrahlen durch sie hindurch in zwei Richtungen zu ermöglichen.

8. Optische Vorrichtung, die eine Kopplungsvorrichtung ist, um die jeweiligen optischen Fasern (110A, 110B) einer Gruppe aus mehreren optischen Fasern an die jeweiligen optischen Wellenleiter (117A, 1178) einer Gruppe aus mehreren optischen Wellenleitern zu koppeln, wobei sich der Abstand der jeweiligen optischen Fasern der Gruppe optischer Fasern vom Abstand der jeweiligen optischen Wellenleiter (117A, 117B) unterscheidet, die ein Substrat zum Befestigen optischer Fasern nach Anspruch 6 umfasst, wobei das Substrat jeweils darin ausgebildete Befestigungsrillen (58A, 58B,60) aufweist, die den jeweiligen optischen Fasern und den jeweiligen optischen Wellenleitern entsprechen, wobei sich ein Ende der jeweiligen Befestigungsrillen an Positionen befindet, die den jeweiligen optischen Fasern entsprechen, wobei sich das andere Ende der jeweiligen Befestigungsrillen an Positionen befindet, die den jeweiligen optischen Wellenleitern entsprechen, wobei die jeweiligen optischen Fasern in den Befestigungsrillen aufgenommen und in diesen befestigt sind und die jeweiligen optischen Fasern und die jeweiligen optischen Wellenleiter verbunden sind, um Nachrichtenverkehr mittels Lichtstrahlen durch sie hindurch in zwei Richtungen zu ermöglichen.

9. Substrat zum Befestigen einer optischen Faser nach Anspruch 1, worin die Befestigungsrille (3) ein Ende (6) aufweist, das in Draufsicht auf eine Hauptfläche gesehen, in der die Befestigungsrille ausgebildet ist, innerhalb des Substrats angeordnet ist, und das Ende eine Endfläche aufweist, die senkrecht zur Hauptfläche verläuft.

10. Optische Vorrichtung, umfassend ein Substrat (64) zum Befestigen einer optischen Faser nach Anspruch 1, wobei ein optischer Wellenleiter (63) oder ein optisches Element auf dem Substrat ausgebildet ist, eine optische Faser in der Befestigungsrille des Substrats aufgenommen und befestigt ist, und eine Endfläche der optischen Faser optisch an den optischen Wellenleiter (63) oder das optische Element gekoppelt ist.

11. Substrat zum Befestigen einer optischen Faser nach Anspruch 1, worin das Substrat (24) einen ersten Vorsprung, worin eine erste genannte Befestigungsrille (3A) ausgebildet ist, einen zweiten Vorsprung, worin eine zweite genannte Befestigungsrille (3B) ausgebildet ist, und einen Verbindungsabschnitt (27) aufweist, der den ersten Vorsprung und den zweiten Vorsprung miteinander verbindet, wobei die erste Befestigungsrille (3A) in einer größeren Höhe über der Oberfläche des Verbindungsabschnitts angeordnet ist als die zweite Befestigungsrille (3B).

12. Optische Vorrichtung, umfassend ein Substrat zum Befestigen einer optischen Faser nach Anspruch 11 sowie eine optische Faser (65A), die in der ersten Befestigungsrille aufgenommen und befestigt ist, und eine optische Faser (65B), die in der zweiten Befestigungsrille aufgenommen und befestigt ist, wobei die optischen Fasern (65A, 65B) optisch miteinander gekoppelt sind.

13. Optische Vorrichtung, umfassend ein Substrat zum Befestigen einer optischen Faser nach Anspruch 11 und ein optisches Element (90), das am Verbindungsabschnitt (27) befestigt ist, wobei sich in Bezug auf die Oberfläche des Verbindungsabschnitts die Höhe eines in das optische Element (90) einfallenden Lichtstrahls von der Höhe eines ausgesendeten Lichtstrahls unterscheidet, der vom optischen Element (90) ausgesandt wird, ein Lichtstrahl-Übertragungs-Element (65A), das in der ersten Befestigungsrille aufgenommen und befestigt ist, sowie ein Lichtstrahl-Übertragungs-Element (65B), das in der zweiten Befestigungsrille aufgenommen und befestigt ist, wobei die Lichtstrahl-Übertragungs-Elemente (65A, 65B) durch das optische Element optisch miteinander gekoppelt sind.

14. Optische Vorrichtung, umfassend ein Substrat zum Befestigen einer optischen Faser nach Anspruch 11, umfassend ein Lichtstrahl-Übertragungs-Element (65A), das in der ersten Befestigungsrille (3A) aufgenommen und befestigt ist, ein Lichtstrahl-Übertragungs-Element (65B), das in der zweiten Befestigungsrille (3B) aufgenommen und befestigt

ist, worin Endflächen (99) der Lichtstrahl-Übertragungs-Elemente zur Ebene senkrecht zur Längsrichtung der Lichtstrahl-Übertragungs-Elemente (65A, 65B) geneigt sind.

15. Durch Formpressen gebildetes Substrat zum Befestigen einer optischen Faser nach Anspruch 1, wobei das Substrat aus einer Glaskeramik besteht, die Glaskeramik einen mittleren Kristallkorndurchmesser nicht über 1,0 μm aufweist, die Hauptkristallphasen Lithiumdisilikat- (Li_2O-$2SiO_2$-) Phase, β-Spodumen- (Li_2O-Al_2O_3-$4SiO_2$-) Phase oder β-Spodumen-Festlösungsphase sind, und der Gehalt der Kristallphasen der SiO_2-Zusammensetzung nicht über 2 Gew.-% liegt.

16. Verfahren zur Herstellung eines Substrats zum Befestigen einer optischen Faser nach Anspruch 1, worin eine Form mit einer Gestalt hergestellt wird, die der Befestigungsrille entspricht, die Rille der Form zu diesem Zeitpunkt durch Schleifarbeit ausgebildet wird und die Form eingesetzt wird, um das Material des Substrats zu pressen.

17. Verfahren zur Herstellung eines Substrats zum Befestigen einer optischen Faser nach Anspruch 1, umfassend das Ausbilden der oder einer jeden Rille (3) und das anschließende Polieren der Rippen und/oder Seitenwände durch Schleifen, so dass sie die genannte Krümmung mit einem Radius nicht unter 5 μm aufweisen.

Revendications

1. Substrat de fixation pour fibre optique (1) ayant au moins une rainure de fixation (3) formée dans le substrat pour recevoir et positionner une fibre optique (9), ladite, ou chaque dite, rainure (3) étant définie par soit

(i) une paire de saillies adjacentes (4), qui chacune sépare deux telles rainures de fixation (3),
(ii) d'un côté une saillie (4) qui sépare deux telles rainures de fixation et du côté opposé une paroi latérale qui joint une surface plane du substrat, et
(iii) une paire de parois latérales opposées, qui chacune joint une surface plane du substrat,

dans lequel l'arrête de chaque dite saillie (4) ou l'arête formée entre chaque dite paroi latérale et la surface plane, tel que cela est représenté dans la section transversale perpendiculaire à la direction longitudinale de la rainure (3), sont arrondies avec un rayon de courbure n'étant pas inférieur à 5 μm.

2. Substrat de fixation pour fibre optique de la revendication 1, dans lequel le fond (5) de la, ou de chaque, rainure de fixation (3) a une courbure de rayon n'excédant pas 5 μm, tel que cela est représenté dans la section transversale perpendiculaire à la direction longitudinale de la rainure.

3. Substrat de fixation pour fibre optique de la revendication 1 ou de la revendication 2, dans lequel le substrat est constitué de verre ou de céramique.

4. Substrat de fixation pour fibre optique de la revendication 1, dans lequel ladite, ou chaque dite, rainure de fixation (3) est formée par formage sous pression.

5. Substrat de fixation pour fibre optique selon la revendication 3, dans lequel ladite rainure de fixation présente une partie courbée (23), telle que représentée sur la vue de dessus, sur le substrat.

6. Substrat de fixation pour fibre optique selon la revendication 5, dans lequel une fibre optique ayant le même profil plan que la rainure de fixation est accueillie et fixée dans la rainure de fixation de telle manière que les contraintes provenant des surfaces inclinées de la rainure de fixation ne soient pas exercées sur la fibre optique.

7. Dispositif optique qui est un dispositif de couplage pour coupler les fibres optiques respectives (59A, 59B) d'un second groupe de fibres optiques où l'espacement des fibres optiques respectives du premier groupe est différent de l'espacement des fibres optiques respectives du second groupe, comprenant un substrat de fixation pour fibre optique (57) selon la revendication 6, le substrat (57) ayant lesdites rainures de fixation (58A, 58B, 60) formées dans celui-ci comme espacements correspondant à une extrémité aux fibres optiques (59A, 59B) du premier groupe et à l'extrémité opposée aux fibres optiques du second groupe, les fibres optiques du premier groupe et les fibres optiques du second groupe étant accueillies et fixées dans les rainures de fixation et étant connectées pour permettre la communication de faisceaux de lumière à travers elles dans les deux directions.

8. Dispositif optique qui est un dispositif de couplage pour coupler les fibres optiques respectives (110A, 110B) d'un groupe de plusieurs fibres optiques aux guides d'ondes optiques respectifs (117A, 117B) d'un groupe de plusieurs guides d'ondes optiques où l'espacement des fibres optiques respectives du groupe de fibres optiques est différent de l'espacement des guides d'ondes optiques respectifs (117A, 117B), comprenant un substrat de fixation pour fibre optique selon la revendication 6, le substrat ayant

des rainures de fixation (58A, 58B, 60) respectivement formées dans celui-ci et correspondant aux fibres optiques respectives et aux guides d'ondes respectifs, une extrémité des rainures de fixation respectives étant située à des emplacements correspondant aux fibres optiques respectives, l'autre extrémité des rainures de fixation respectives étant située à des emplacements correspondant aux guides d'ondes optiques respectifs, les fibres optiques respectives étant accueillies et fixées dans les rainures de fixation, et les fibres optiques respectives et les guides d'ondes respectifs étant connectés pour permettre la communication de faisceaux de lumière à travers ceux-ci dans les deux directions.

9. Substrat de fixation pour fibre optique selon la revendication 1, dans lequel la rainure de fixation (3) a une extrémité (6) située dans le substrat, tel que cela est représenté sur une vue de dessus, sur une surface principale, dans laquelle la rainure de fixation est formée, et l'extrémité a une surface d'extrémité qui est perpendiculaire à ladite surface principale.

10. Dispositif optique comprenant un substrat de fixation pour fibre optique (64) selon la revendication 1, ayant un guide d'ondes optique (63) ou un élément optique formés sur le substrat, une fibre optique accueillie et fixée dans la rainure de fixation du substrat et une surface d'extrémité de la fibre optique étant optiquement couplée au guide d'ondes optique (63) ou à l'élément optique.

11. Substrat de fixation pour fibre optique selon la revendication 1, dans lequel le substrat (24) présente une première protubérance, dans laquelle une première dite rainure de fixation (3A) est formée, une seconde protubérance dans laquelle une seconde dite rainure de fixation (3B) est formée et une partie de connexion (27) connectant la première protubérance et la seconde protubérance, la première rainure de fixation (3A) étant positionnée à une hauteur plus élevée au-dessus de la surface de la partie de connexion que la seconde rainure de fixation (3B).

12. Dispositif optique comprenant un substrat de fixation pour fibre optique selon la revendication 11 et une fibre optique (65A) accueillie et fixée dans la première rainure de fixation et une fibre optique (65B) accueillie et fixée dans la seconde rainure de fixation, les fibres optiques (65A, 65B) étant optiquement couplées l'une à l'autre.

13. Dispositif optique comprenant un substrat de fixation pour fibre optique selon la revendication 11 et un élément optique (90) fixé à la partie de connexion (27), la hauteur d'un faisceau de lumière incident dans l'élément optique (90) étant différente de la hauteur d'un faisceau de lumière d'émission émis par l'élément optique par rapport à la surface de la partie de connexion, un élément de transmission de faisceau de lumière (65A) accueilli et fixé dans la première rainure de fixation, un élément de transmission de faisceau de lumière (65B) accueilli et fixé dans la seconde rainure de fixation, les éléments de transmission de faisceau de lumière (65A, 65B) étant optiquement couplés l'un à l'autre par l'intermédiaire de l'élément optique.

14. Dispositif optique comprenant un substrat de fixation pour fibre optique selon la revendication 11, comprenant un élément de transmission de faisceau de lumière (65A) accueilli et fixé dans la première rainure de fixation (3A), un élément de transmission de faisceau de lumière (65B) accueilli et fixé dans la seconde rainure de fixation (3B), dans lequel les surfaces d'extrémité (99) des éléments de transmission de faisceau de lumière sont inclinées par rapport au plan perpendiculaire à la direction longitudinale des éléments de transmission de faisceau de lumière (65A, 65B).

15. Substrat de fixation pour fibre optique de la revendication 1 formé par formage sous pression, dans lequel le substrat est constitué de vitrocéramique, le substrat en vitrocéramique ayant un diamètre de grain cristallin moyen n'excédant pas 1,0 μm, les principales phases cristallines étant une phase de disilicate de lithium (Li_2O-$2SiO_2$), une phase de spodumène β (Li_2O-Al_2O_3-$4SiO_2$) ou une phase de solution solide de spodumène β, et la teneur des phases cristallines de la composition en SiO_2 n'excédant pas 2 % en masse.

16. Procédé de fabrication d'un substrat de fixation pour fibre optique selon la revendication 1, dans lequel un moule ayant une forme qui correspond à la rainure de fixation est préparé, la rainure du moule est préparée à ce moment là par un travail par abrasion, et le moule est utilisé pour presser le matériau du substrat.

17. Procédé de fabrication d'un substrat de fixation pour fibre optique selon la revendication 1, comprenant la formation de la rainure ou de chaque rainure (3) puis le polissage des saillies et/ou des parois latérales par abrasion, de telle manière qu'elles aient ladite courbure de rayon qui ne soit pas inférieure à 5 μm.

FIG_1a
PRIOR ART

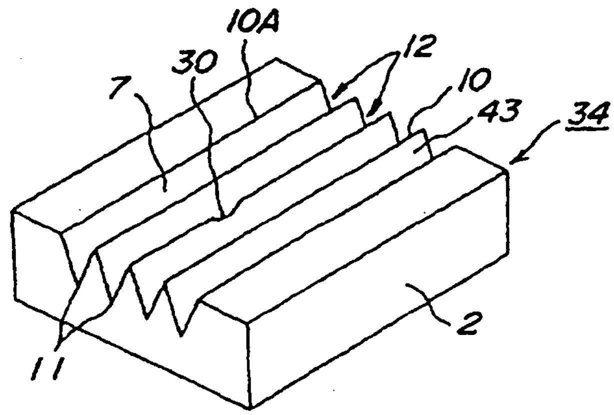


FIG_1b
PRIOR ART

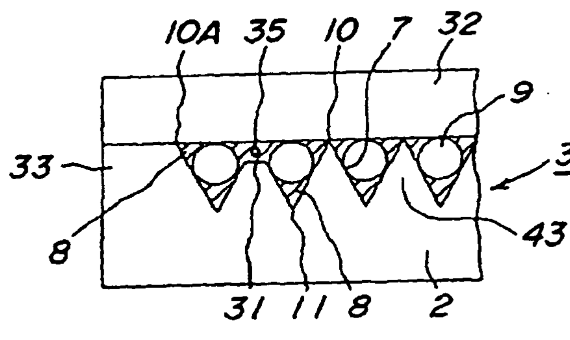


FIG. 2a

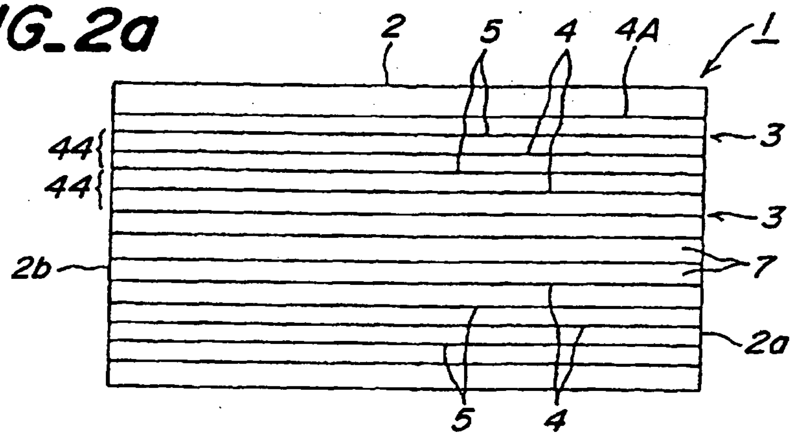


FIG. 2b

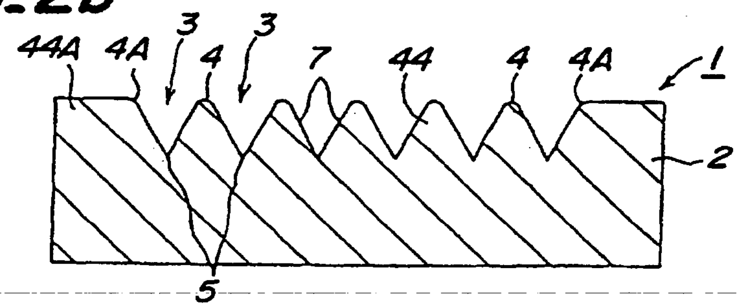


FIG. 2c

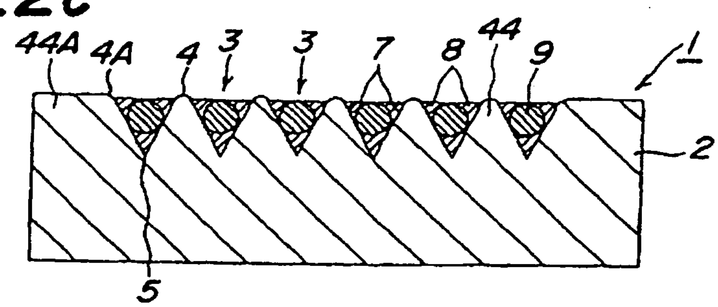


FIG_3 PRIOR ART

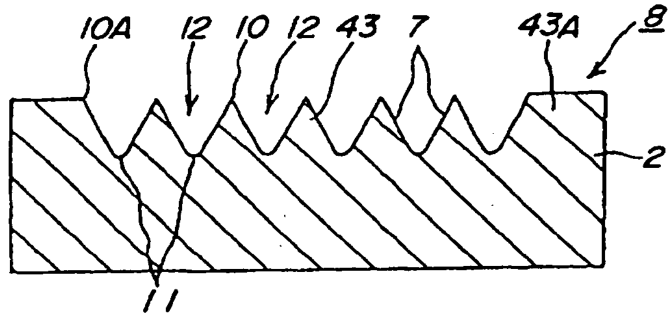


FIG_4

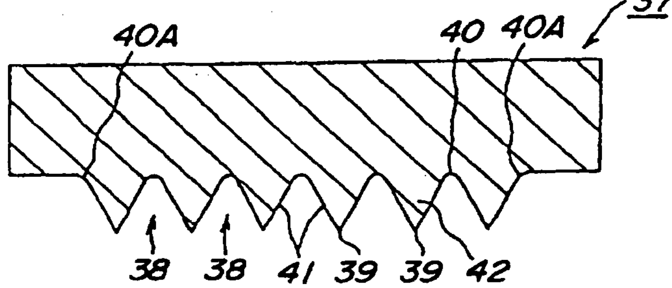


FIG_5

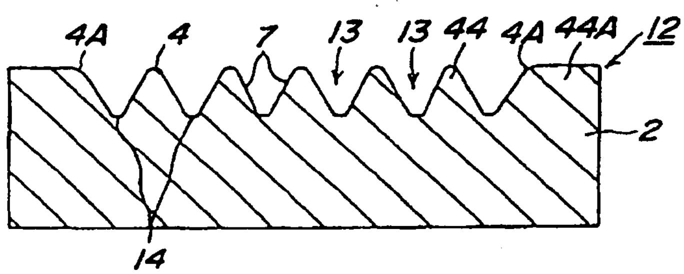


FIG_6

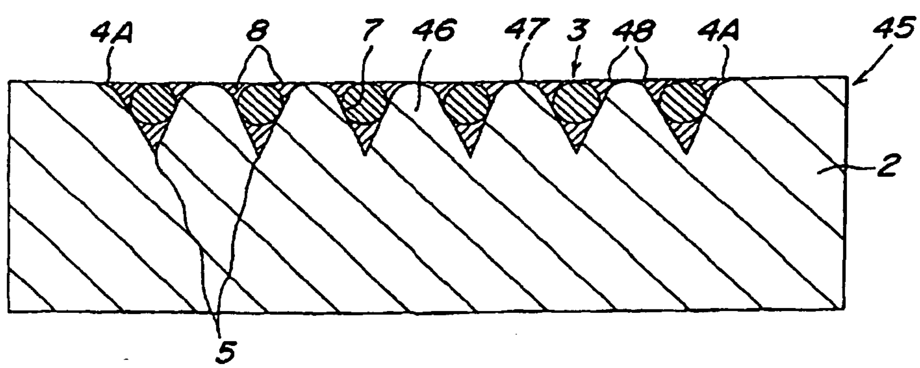


FIG_7a

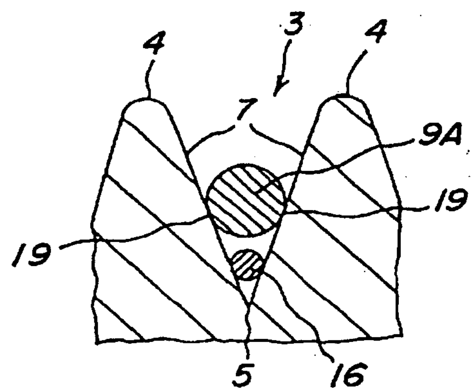


FIG_7b

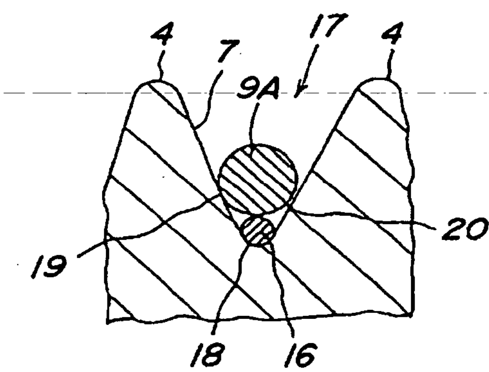


FIG.8a

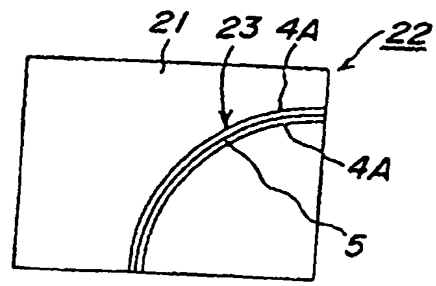


FIG.8b

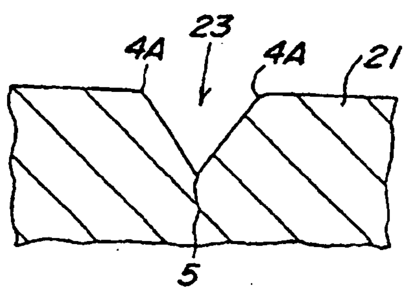


FIG.9a

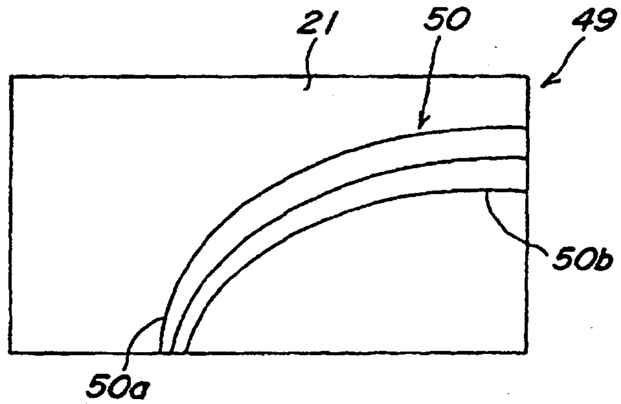


FIG.9b

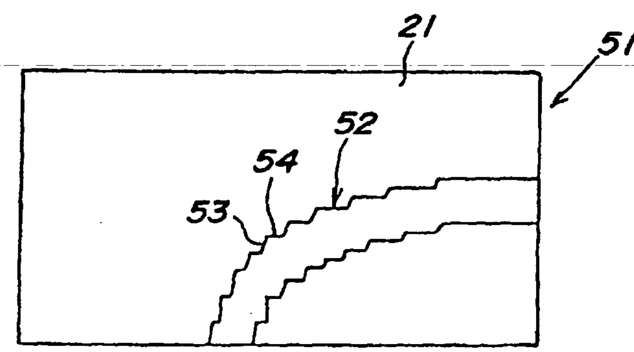


FIG_10a

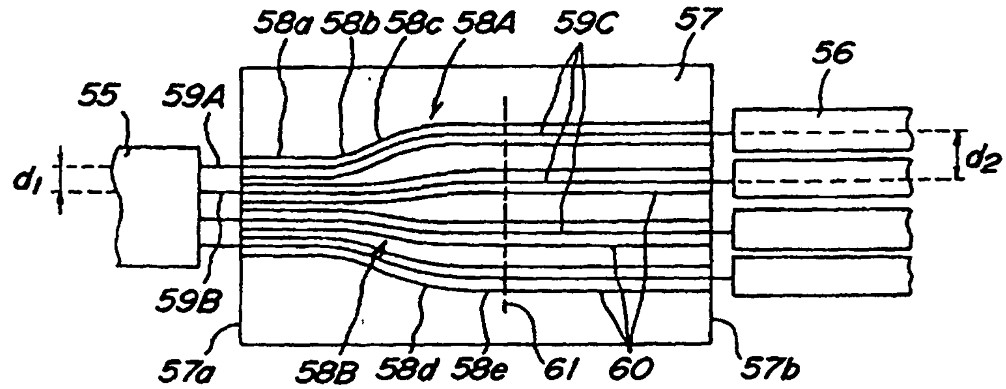


FIG_10b

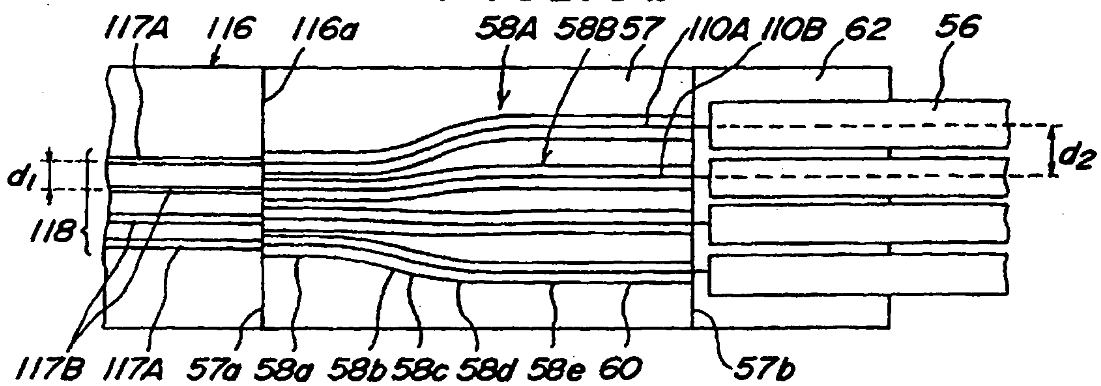


FIG_10c

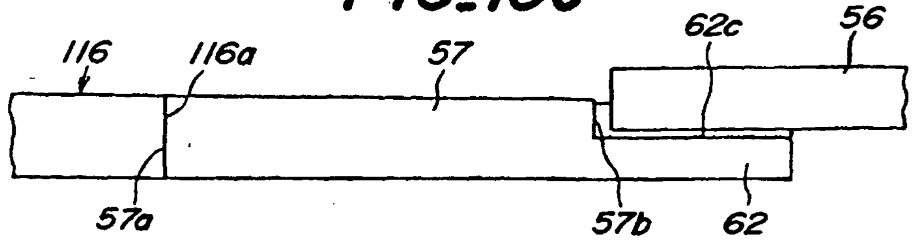


FIG_11a

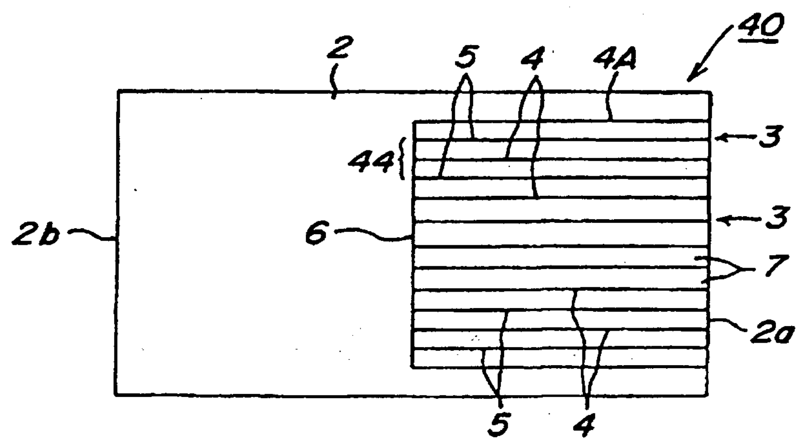


FIG_11b

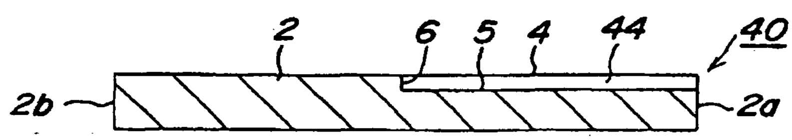


FIG_12a

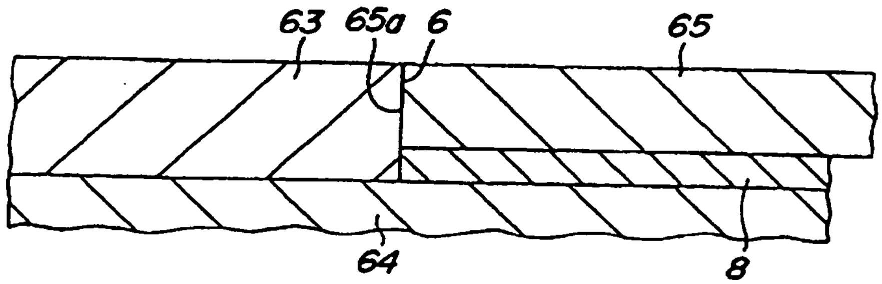


FIG_12b

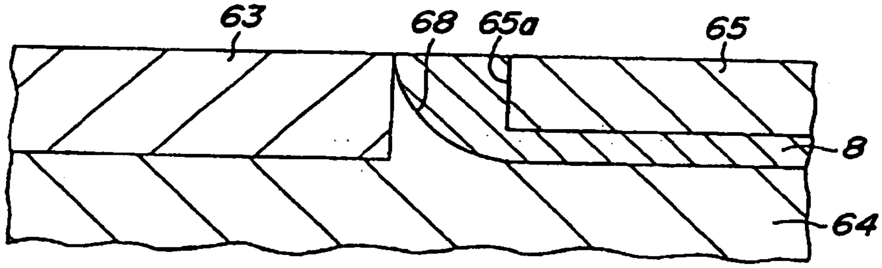


FIG_12c

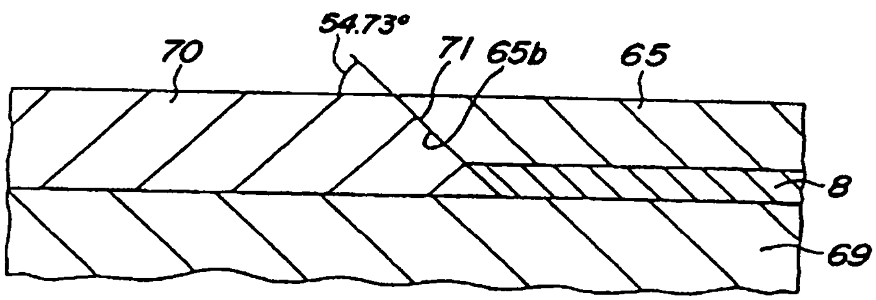


FIG_13

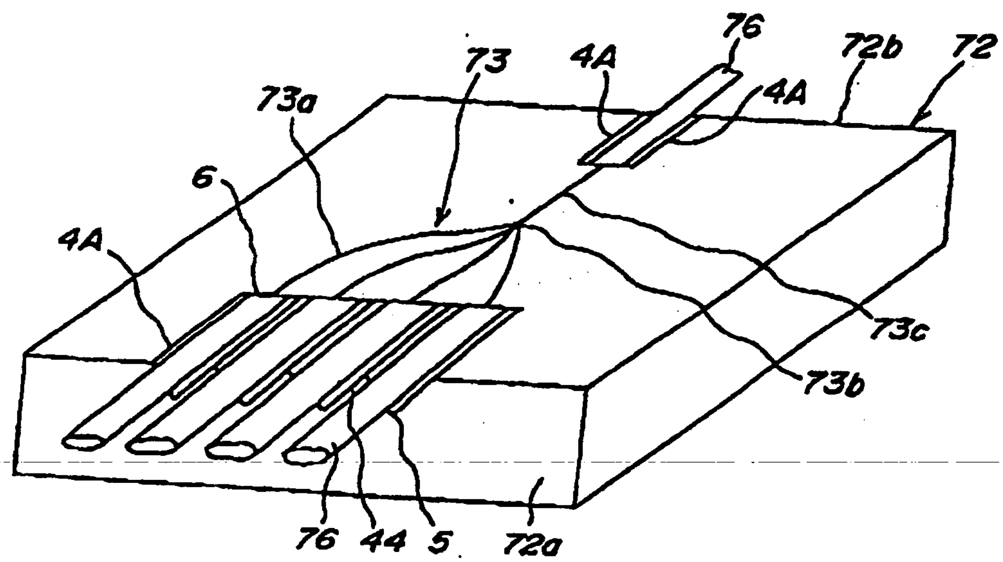


FIG_14

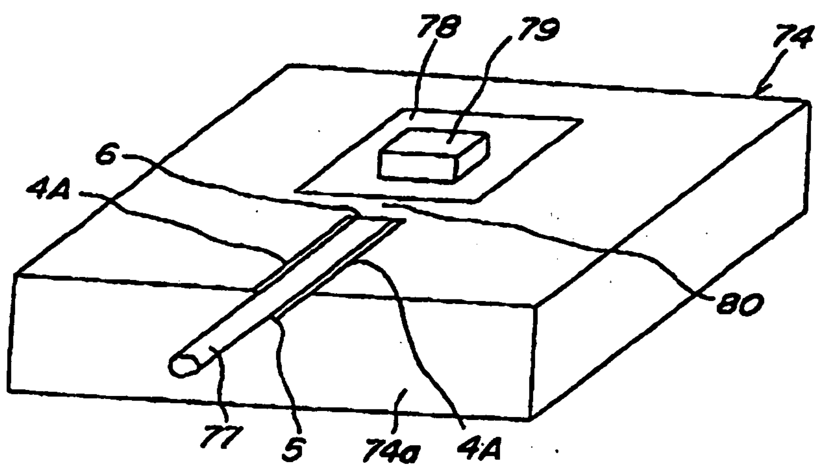


FIG_15a

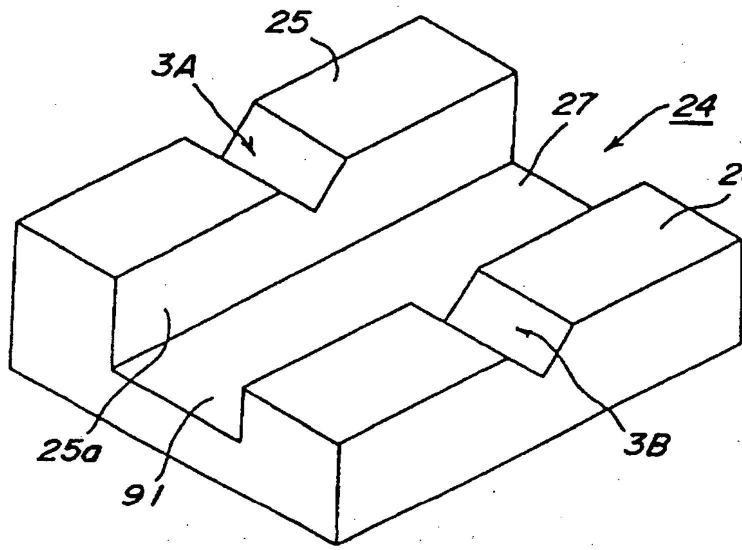


FIG_15b

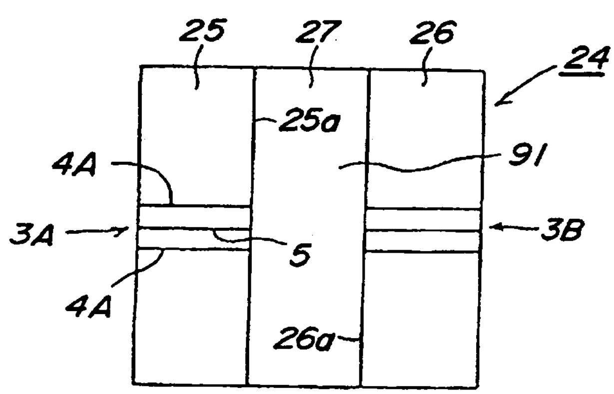


FIG_16a

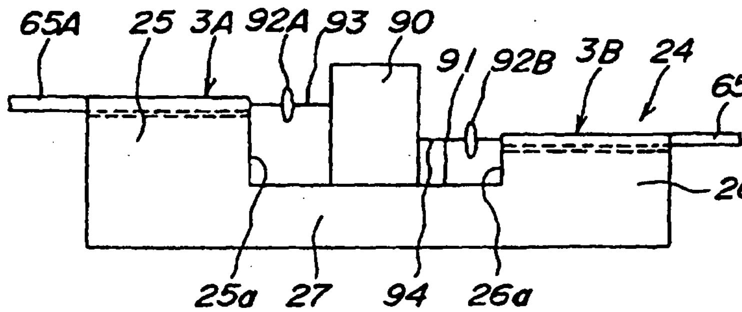


FIG_16b

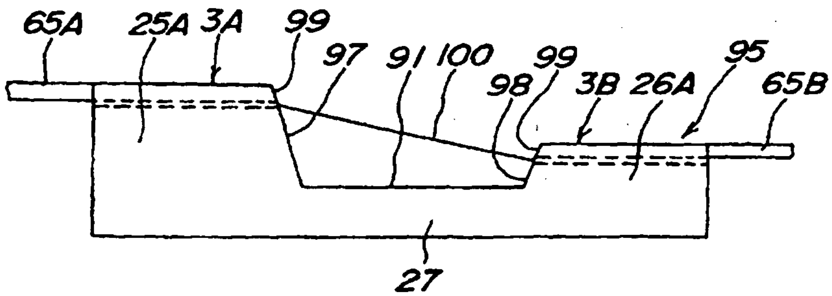


FIG_16c

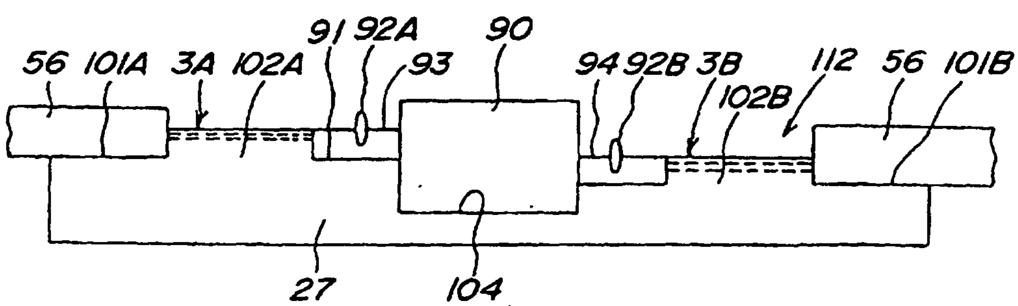


FIG.17

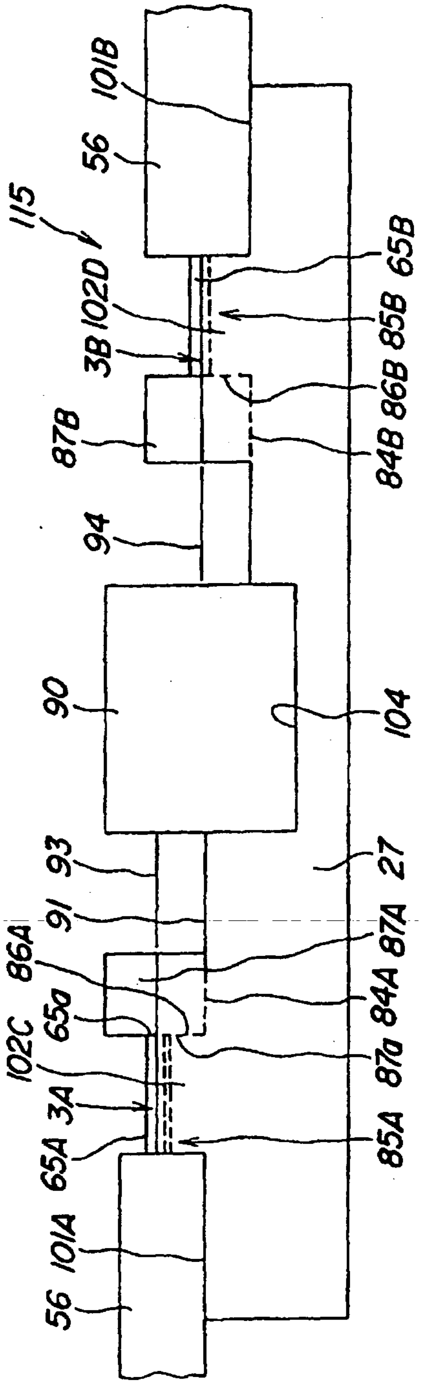

56
101B
115
102D
65B
85B
3B
86B
84B
87B
94
90
104
93
27
91
86A
87A
65a
84A
102C
87a
3A
65A
85A
101A
56

FIG_18a

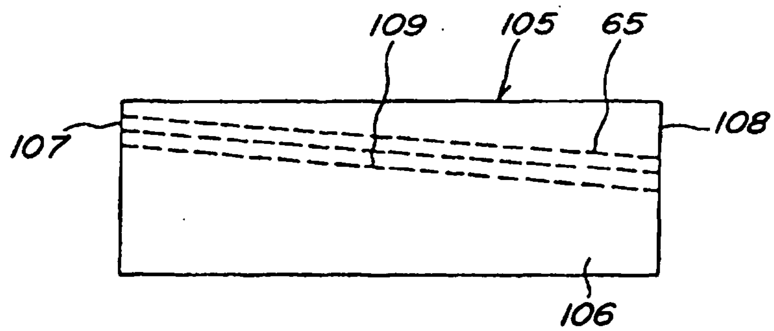


FIG_18b

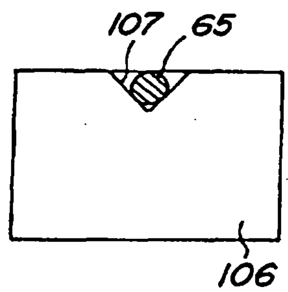


FIG_18c

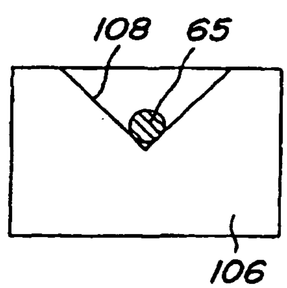


FIG_19

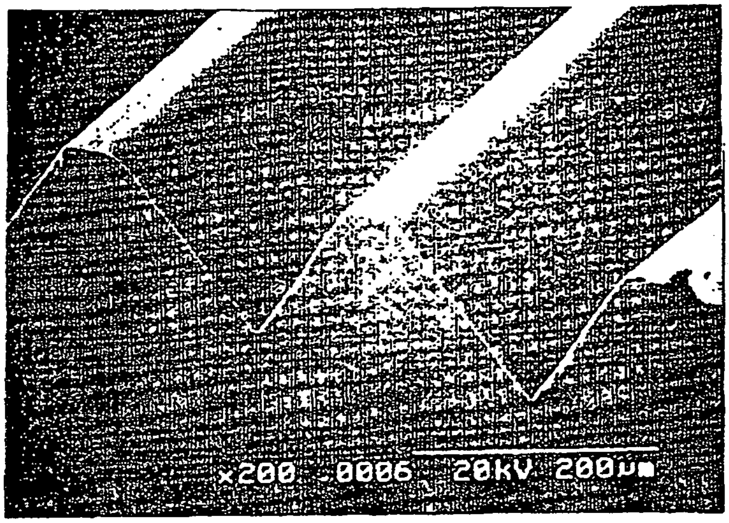
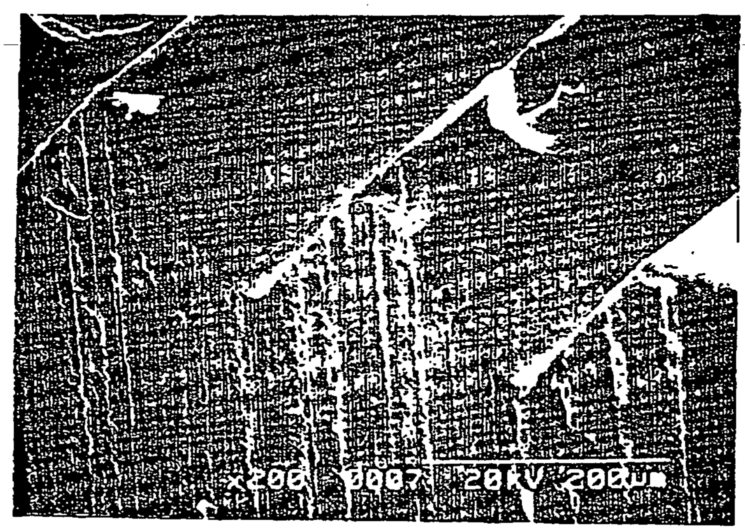


FIG_20
PRIOR ART



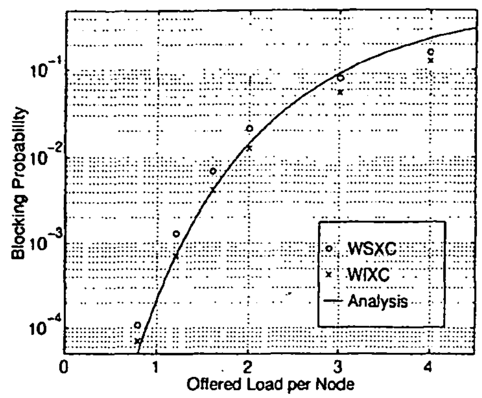


Figure 8: The load-dependence of the blocking probability for the bidirectional ring network with $M = 1$, $N_t = 10$.

6 Conclusion

We compared wavelength-selective (WS) and wavelength-interchanging (WI) cross-connects in multiwavelength all-optical networks. We quantified the benefits of wavelength interchanging in terms of blocking probability and required capacity. The utilization gain derived from probability analysis of blocking in a dynamic path set-up approximates well the link-complexity ratio attained from capacity assignment. We extended Barry's probability analysis to the multifiber case. The probability analysis yields the following insights. Keeping everything else the same, increasing H (the average hop-count) or decreasing L (the interference length, defined as the average number of common links between paths that share links) favors WI. A large K (the number of wavelengths) weakly favors WI while a large M (the number of fibers) favors WS strongly. In other words, the number of fibers is more important than the number of wavelengths, and the multifiber links dwarf the advantages of WI. The gain of wavelength-interchanging decreases rapidly with increasing traffic per node pair mainly because of the increased number of fibers to meet the traffic demand, and partly because of the increased interference length. For a given traffic demand and a specified blocking probability, a mesh network enjoys a higher utilization gain of WI than a ring or a fully connected network.

Appendix A

We first consider the blocking probability in the network without interchanging wavelength. If we denote the probability that no channel on wavelength λ is available on link i as q_i, then the wavelength is used on the next link $i+1$ with probability $q_{i+1} = (1-q_i)P_n + q_i(1 - P_l + P_l P_n)$ conditioned on the usage of the wavelength on link i. Here, P_n is the conditional probability that a node adds new paths to fill the channels on λ completely, given that at least one of the channels on λ is available on the previous link, and P_l the conditional probability that some paths on λ drops out of a node, given that all the channels on λ are used on the previous link. The index i can be dropped $(q_i = q_{i+1} = q)$ if we assume these probabilities are equal on all links and all wavelengths. If each link consists of independent M fibers, q is equal to ρ_{ws}^M, where ρ_{ws} is the probability that a wavelength is used on a fiber. Thus,

$$\rho_{ws} = q^{1/M} = \left[\frac{P_n}{1-(1-P_l)(1-P_n)}\right]^{\frac{1}{M}}. \tag{7}$$

A WS path can be set up with probability $(1-P_n)^H$ when a wavelength is available on all H links. On the other hand, a path is blocked when every wavelength is blocked, so the blocking probability for a WS path is

$$P_b = [1-(1-P_n)^H]^K. \tag{8}$$

Note an achievable utilization of a fiber for a blocking probability has been increased by a factor of $1/(P_n + P_l - P_n P_l)$. From the definition, the interference length is given by

$$L = \sum_{h=1}^{H} h(1-P_l)^{h-1}P_l = \frac{1}{P_l} - \left(H + \frac{1}{P_l}\right)(1-P_l)^H, \tag{9}$$

which can be approximated as $P_l \sim 1/L$ for a sufficiently large H. From (7), (8), and (9), the utilization of a WS link is given by

$$\rho_{ws} \sim \left[\frac{1-(1-P_b^{1/K})^{1/H}}{1-(1-P_b^{1/K})^{1/H}\left(1-\frac{1}{L}\right)}\right]^{\frac{1}{M}}. \tag{10}$$

Since it is shown that the effect of the interference length is very weak on a WI link utilization [3], $\rho_{wi} = \rho_i$, and the utilization gain is given by

$$G \sim \frac{\rho_i}{\rho_s}\left\{1-(1-\rho_s^M)\left(1-\frac{1}{L}\right)\right\}^{\frac{1}{M}}, \tag{11}$$

where $\rho_s = [1-(1-P_b^{1/K})^{1/H}]^{1/M}$ and $\rho_i = [1-(1-P_b)^{1/H}]^{1/MK}$.

Appendix B

Let us define a shared-link matrix $S = [S_{(jk)(lm)}]$, where $S_{(jk)(lm)}$ is the number of links shared by a route (j,k) and a route (l,m). And also define a link-sharing-indication matrix $I = [I_{(jk)(lm)}]$, where $I_{(jk)(lm)} = 1$ if $S_{(jk)(lm)} > 0$, and otherwise $I_{(jk)(lm)} = 0$. Both of the above matrices are symmetric. We enumerate each route (j,k) with a single index so that we can express the above

matrices as S_{ij} and I_{ij}. Assume every route carries t optical paths, where this paper distinguishes a route from an optical path. Since S_{ii} indicates the length of path i, the average hop count is given by

$$H = \frac{\sum_i^P S_{ii}}{\sum_i^P I_{ii}} = \frac{trS}{trI}. \quad (12)$$

There are $t(t-1)/2$ different pairs of paths chosen from a single route, and t^2 pairs, each of a pair chosen from route i and from route j, which share S_{ij} links. Thus, the interference length, the average number of links shared by two optical paths which share some links, is given by

$$L = \frac{2t^2 \sum \sum_{i<j} S_{ij} + t(t-1)trS}{2t^2 \sum \sum_{i<j} I_{ij} + t(t-1)trI}, \quad (13)$$

where $P = trI$ is the total number of routes. $P = N_t(N_t - 1)$ when a forward route (j, k) and a backward route (k, j) are different, and $P = N_t(N_t - 1)/2$ if they are equal, where N_t is the number of nodes. L is greater than or equal to one if $t \geq 1$. (13) can be recast into

$$L = L_\infty - (L_\infty - L_1)\frac{1-a}{t-a}, \quad (14)$$

where $a = trI/(\sum \sum_{i \neq j} I_{ij} + trI)$, $L_1 = \sum \sum_{i \neq j} S_{ij} / \sum \sum_{i \neq j} I_{ij}$, and

$$L_\infty = \frac{\sum \sum S_{ij}}{\sum \sum I_{ij}} = H \left(\frac{1 + \frac{\sum \sum_{i \neq j} S_{ij}}{trS}}{1 + \frac{\sum \sum_{i \neq j} I_{ij}}{trI}} \right). \quad (15)$$

Since $S_{ij} \leq \min(S_{ii}, S_{jj})$, the average off-diagonal element of S is smaller than its average diagonal element, $\sum \sum S / \sum \sum I \leq \mathrm{tr}S/\mathrm{tr}I$, and thus

$$1 \leq L \leq L_\infty \leq H. \quad (16)$$

In the case of a large K, the number of wavelengths, the utilization can be expressed as

$$G \sim \left[\frac{H}{L_\infty} \left(1 + \frac{(1-a)(1 - L_\infty/L_1)}{t - a - (1-a)(1 - L_\infty/L_1)} \right) \right]^{\frac{1}{M}}. \quad (17)$$

Equation (17) predicts that as traffic size t increases, L increases toward L_∞ and G drops converges down to $(H/L_\infty)^{(1/M)}$, which is determined by a network topology and a routing method. The utilization gain is small if most off-diagonal elements of I are zero as for a fully connected graph. A fully connected topology has S and I equal to the identity matrix, thus $L = 1$, $H = 1$ and $G = 1$, regardless of t or N_t, the number of nodes. A unidirectional ring network has $H = N/2$, $L_1 = (7N-1)/20$ and $L_\infty = (7N-2)(N-1)/(20N-28)$. A bidirectional ring has a smaller H/L_∞ than a unidirectional one. A star network has $H = 2(N-1)/N$, $L_1 = 1$, and $L_\infty = 2(N-1)^2/(2N^2 - 5N + 4)$. At heavy traffic, the gain is determined by the factor in the parenthesis of (15), which is equal to H/L_∞. Note that this gain does not scale with the network size, N_t, for the above three networks.

References

[1] K. Sato, "Network performance and integrity enhancement with optical path layer technologies," *Journal on Selected Areas of Communications*, Vol. 12, pp. 159-170, 1994.

[2] S. B. Alexander et al., "A precompetitive consortium on wide-band all-optical networks," *Journal of Lightwave Technology*, Vol. 11, pp. 714, 1993.

[3] R. A. Barry and P. A. Humblet, "Models of blocking probability in all-optical networks with and without wavelength changers," *Proceedings of IEEE INFOCOM '95*, Vol. 2, pp. 402-412, 1995.

[4] M. Kovacevic and A. Acampora, "On wavelength translation in all-optical networks," *Proceedings of IEEE INFOCOM '95*, Vol. 2, pp. 413-422, 1995.

[5] I. Chlamtac et al., "Lightpath communications: An approach to high bandwidth optical WANs," *IEEE Transactions on Communications*, Vol. 40, pp. 1171-1182, 1992.

[6] N. Wauters and P. Demeester, "Wavelength requirements and survivability in WDM cross-connected networks," *Proceedings of ECOC '94*, Vol. 2, pp. 589-592, 1994.

[7] C.A. Brackett et al., "A scalable multiwavelength multihop optical network," *Journal of Lightwave Technology*, Vol. 11, pp. 736-753, 1993.

[8] G. Jeong and J. W. Goodman, "Gain optimization in switches based on semiconductor optical amplifiers," *Journal of Lightwave Technology*, Vol. 13, pp. 598-605, 1995.

[9] M. Erman and J.-F. Vinchant, "Semiconductor digital optical switchies and arrays," *OFC '94 Technical Digest*, Vol. 4, pp. 53, 1994.

[10] K. Lee and V. O. K. Li, "Routing and switching in a wavelength convertible optical network," *Proceedings of IEEE INFOCOM '93*, Vol. 2, pp. 578-585, 1993.

[11] J. Y. Hui, *Switching and Traffic Theory for Integrated Broadband Networks*, Kluwer Academic Publishers, 1990.